RESEARCH BULLETIN NO. 7. -13

THE UNIVERSITY OF NEBRASKA.

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA.

A GENETIC STUDY OF PLANT HEIGHT IN PHASEOLUS VULGARIS.

By R. A. EMERSON.

DISTRIBUTED MARCH 15, 1916 -15

LINCOLN, NEBRASKA
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CONTENTS.

SUMMARY.

It is pointed out in this paper that many quantitative characters of plants blend in F_1 of crosses and exhibit a wide range of variation in F_2, from which types like the parents—or perhaps even more extreme—and various intermediate forms can be isolated in F_3. Height of some plants is known to behave in this way. It is noted also that some quantitative characters, particularly height of several distinctly different plants, exhibit dominance instead of an intermediate condition in F_1, followed by a 3:1 segregation in F_2 and simple Mendelian behavior in later generations. When pole and bush beans are crossed, 3:1 segregation results whether the pole bean is very tall or only medium in height and whether the bush bean is very short or relatively tall. To determine the interrelation of these two types of behavior by an analysis of the factors concerned in height of plants in beans and by a study of their mode of inheritance was the object of the investigations reported here.

Mendel reported simple 3:1 segregation in F_2 of crosses of tall and dwarf beans, both when the races concerned belonged to one species, *Phaseolus vulgaris,* and when one of them belonged to another species, *P. multiflorus.* The results of von Tschermak, with crosses between dwarf races of the former species and a tall race of the latter one, were by no means so simple as those reported by Mendel and were thought to be due in part at least to the action of more than one genetic factor. Results previously reported by the writer demonstrated simple Mendelian behavior in crosses between "pole" and "bush" habits of growth in *Phaseolus vulgaris.*

The methods employed by the writer in making crosses, growing the plants, protecting them from cross-pollination by insects, making records, etc., as described in detail in the body of this paper, are believed to have been sufficiently careful to make the results reliable as a whole.

Pole and bush beans are shown to differ in a single character, habit of growth. Bush beans are determinate in growth habit. The main axis is terminated by an inflorescence when from about four to eight internodes have developed and cannot be forced to make any further growth tho provided with the most favorable conditions of moisture and temperature, and even tho the flowers be removed to prevent the drain of seed production. Pole beans are indeterminate in growth habit. The first flower

clusters appear at about the fifth to the eighth node and the others progressively higher as new internodes are added. Growth of the axis is terminated only by accident, unfavorable surroundings, the drain of seed production, and the like. If favorable conditions for growth are provided and if heavy seed production is prevented, pole beans can be kept growing for a long time if not indefinitely. Plants of both classes grow slowly at first and then increasingly more rapidly. In bush beans growth is terminated early in this period of acceleration in growth rate. In pole beans acceleration in growth rate continues for a considerable time, but retardation in growth rate occurs eventually because of the drain of seed production, increasingly unfavorable weather conditions late in the season, and the like.

The twining habit common in pole beans is also exhibited by the taller bush beans when they are forced into very vigorous growth. Its failure to develop in bush beans as a whole is due to the fact that growth of the axis is terminated too soon.

While bush beans are commonly more branched than pole beans, there are great differences within both classes with respect to this, so that branching habit cannot be used to characterize the classes.

Pole and bush beans also differ in height in consequence of the difference in habit of growth. Obviously, height of plants depends upon number of internodes and internode length. Bush beans have a short axis in part because of a small number of internodes and in part also because of a relatively small mean internode length, the latter being due to termination of the plant axis early in the period of growth-rate acceleration. Pole and bush beans, then, are characterized by differences in height, only in so far as height is dependent upon determinate and indeterminate habits of growth. Races of bush beans differ materially in height and the same is true of pole beans.

Since the axis of a bush bean is terminated early in the period of growth-rate acceleration, its actual internode length s considerably less than its potential internode length. The latter can be determined only by crossing the bush bean with a pole bean and by comparing the internode length of the plants of indeterminate growth habit thus produced with that of the pole-bean parent or by comparing both with some other pole bean used as a standard.

The F_2 pole-bean segregates of such crosses are better for this purpose than the F_1 plants, because increased vigor due to heterozygosis is much less in F_2 than in F_1. By comparing the potential internode lengths of bush beans, as determined by this method, with the actual internode lengths of these bush beans, it is found

that potential internode length can be determined roughly from actual internode length of the first five internodes of bush beans. It is also found possible to determine with fair accuracy the internode length of pole beans by measuring the first 15 internodes, which usually include the greater part of those formed during the period of growth-rate acceleration.

It is shown that indeterminate habit of growth in beans is fully dominant to determinate habit, that sharp segregation occurs in F_2 resulting in a ratio of three plants of indeterminate habit to one of determinate habit, and that determinate habit is constant in F_3 while some indeterminate F_2 plants breed true in F_3 and others segregate again into pole and bush plants. The difference between indeterminate and determinate habits of growth is, therefore, due to a single genetic factor.

While number of internodes is directly, and internode length indirectly, related to habit of growth, these characters are in a way distinct from it. There exist distinct types of bush beans with respect to both number of internodes and internode length. The same is true of pole beans.

Crossing bush beans of different internode lengths is shown to result in an intermediate condition in F_1 and a wider range of variation in F_2 with respect to internode length. The same results are secured from crosses between pole beans of different internode lengths.

A cross between a short pole bean and a tall bush bean is shown to produce tall pole beans in F_1. F_2 consists, on the average, of three pole beans to one bush bean, but some of the pole-bean segregates have fewer and shorter internodes than the pole-bean parent and some of the bush-bean segregates have more and longer internodes than the bush-bean parent.

The same results are shown to follow when a tall pole bean is crossed with a short bush bean. From the F_2 bush segregates of such a cross there has been established a bush-bean race that has more and much longer internodes than the bush-bean parent race.

The dominance of indeterminate over determinate habit of growth in a cross between pole and bush beans and the simple 3-1 segregation in F_2 are interpreted just as other simple Mendelian results are, namely, on the basis of a single dominant, genetic factor for the difference between the parents in habit of growth. The intermediate height in F_1 and the wide range of variation in F_2, from a cross between two bush beans or between two pole beans of different heights, are interpreted in accordance with the multiple-factor hypothesis, which postulates that hereditary, quantitative differences are due to two or more non-

dominant, independently inherited factors. The segregation into three plants with indeterminate habit to one with determinate habit accompanied by an increased range of variation in height of both classes of segregates, when a short pole bean is crossed with a tall bush bean or a tall pole bean with a short bush bean, are, therefore, interpreted by a combination of the single-factor and the multiple-factor hypotheses, or by what may be termed a modified multiple-factor hypothesis, the modification consisting merely in the assumption of inequality in dominance and inequality in potency between the factors. One dominant factor is assumed to determine habit of growth and therefore to have a much greater potency in the determination of plant height than the two or more other, nondominant factors.

It is argued that this modified multiple-factor hypothesis affords a more simple and direct interpretation of the results in bean crosses than does the hypothesis of a single unit-difference between all pole and bush beans, which necessitates the further assumption that the unit-factor is modified commonly, tho irregularly, in crosses between pole and bush beans.

A GENETIC STUDY OF PLANT HEIGHT IN PHASEOLUS VULGARIS.[1]

By R. A. Emerson.[2]

INTRODUCTION.

It is now coming to be expected generally that crosses between plant races that differ in quantitative characters will be intermediate between their parents in F_1 with respect to such characters, that they will exhibit a wide range of variation in F_2, and that from these F_2 segregates the parent types and various intermediate forms can be isolated in F_3 or later generations. Over three years ago Emerson and East (1913) presented evidence that no less than 11 quantitative characters in *Zea mays* are inherited in this manner. In the same paper there were reviewed similar results of seven investigations having to do with some twenty quantitative characters in several distinct groups of plants.

Some crosses between plants that differ much in size have seemed not to follow the behavior outlined above. Notable examples of this sort are crosses between tall and dwarf peas (Mendel 1865, Lock 1905, Keeble and Pellew 1910), between tall and dwarf tomatoes (Hedrick and Booth 1907, Price and Drinkard 1908, and Gilbert 1912), between tall and dwarf sweet peas (Bateson and Punnett 1908), between tall and dwarf beans (Mendel 1865 and Emerson 1904), and between tall and dwarf maize (East and Hayes 1911 and Emerson 1911). In all these cases perfect dominance of tallness over dwarfness in F_1 and simple 3-1 segregation in F_2 have been reported.[3]

The distinctness of these two classes of behavior with respect to what have seemed to be solely quantitative differences gives them a special importance. Interest in them is heightened by the fact that different quantitative characters of even the same plants are found to belong to the two distinct classes of behavior. Thus, size of seeds in beans belongs to the first class of behavior

[1]This paper was written in approximately its present form early in 1913. The original manuscript has been modified slightly by the addition of data and by references (mostly in footnotes) to recent papers bearing upon the matter under discussion.

[2] Resigned September, 1914, to become head of the Department of Plant Breeding, Cornell University, Ithaca, New York.

[3] Other characters beside tallness and dwarfness are concerned in some of these cases, namely, erect and prostrate habit in sweet peas (Bateson and Punnett 1908) and stout and slender stems in peas (Keeble and Pellew 1910).

(Emerson 1910), while height of plants has been put in the second class. In certain crosses between tall and dwarf maize one type of behavior results, and in other crosses the other type is exhibited.

Intermediate development in F_1 and a wide range of variation in F_2, characteristic of one of these classes, is now interpreted rather generally, tho by no means universally, [1] by the multiple-factor hypothesis, which postulates that, external influences aside, quantitative differences depend upon two or more independently inherited, nondominant,[2] genetic factors—a strictly Mendelian interpretation. Quantitative differences that show dominance in F_1, followed by a 3-1 segregation in F_2, must depend upon a single dominant, genetic factor or upon factors that are coupled in inheritance. That some quantitative differences are due to a single factor while others are due to many factors need not, it might seem at first, occasion any wonder. In maize, for instance, seeds may differ much or little in breadth. When the parents of a cross differ much, many more individuals must be grown in F_2 than when they differ little, if the parent sizes are to be recovered. In other words large differences in breadth of seeds appear to be due to more factors than do small differences. Is it not to be expected, then, that some differences may be due to a single factor?

The fact of prime importance in this connection is that both large and small quantitative differences in the same plant parts seem to depend upon a single factor. Thus, in crosses between pole beans and bush beans, the F_1 plants are always pole beans and the F_2 plants consist of approximately three pole beans to one bush bean. This is equally true whether the pole bean parent normally grows to a height of say 12 feet or only to a height of 6 feet and whether the bush bean is 2 feet or only 9 inches high. What happens when a tall bean is crossed with a very tall one? What results are to be expected from a cross between a short bean plant and a very short one? How does a cross between a tall bean and a short one differ from a cross between a very tall bean and a very short one? To answer these and similar questions was the purpose of the investigations reported here.

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[1] For an interpretation based upon the assumption that genetic factors are commonly modified in crosses see Castle 1912 and 1914a.

[2] Both Shull (1914) and Muller (1914) have shown that lack of dominance is not essential to the multiple-factor hypothesis (referred to by Shull as the hypothesis of plural genes). Shull's argument is based upon the assumption of the possible interaction of dominant factors of opposite effect, as an inhibitor and a stimulator. Muller's contention is practically the same but is stated in terms of plus and minus dominant factors. A third form of statement for the same results is that part of the positive factors may be fully dominant and part wholly recessive.

This account deals with beans alone. Similar investigations are under way with maize in which are concerned both large and small "dwarfs" as well as "tall" plants of various heights. These studies have not been completed, but it seems unlikely that the results can be interpreted in quite the same way as are the results with beans.

PREVIOUS INVESTIGATIONS.

Mendel (1865) reported the results of a cross between a tall form of the common bean, *Phaseolus vulgaris*, 10-12 feet high, and a dwarf form of the same species (known then as *P. nanus*). He found tallness dominant to dwarfness in F_1 and approximately three tall plants to one dwarf plant in F_2. All F_2 dwarfs remained constant in F_3, as did some of the talls, while the rest of the F_2 talls segregated again in F_3. Mendel also crossed a dwarf form of the common bean with a tall, twining form of the runner bean, *P. multiflorus*. Owing to partial sterility, comparatively few individuals of this cross were grown. The results, however, were in very close agreement with those obtained from the cross between tall and dwarf forms of the common bean. In short, Mendel's results with beans were of the same sort as those of his more extensive and better known experiments with peas.

Von Tschermak (1904) also crossed a dwarf race of *P. vulgaris* with a tall race of *P. multiflorus*. Here again tallness was dominant, tho somewhat weakened, in F_1, but the results in F_2 were very different from those reported by Mendel. Of 144 F_2 plants only 26 were classified as tall and 118 were short, or a ratio of 1:4.5 where a 3:1 ratio was to have been expected. Of the short F_2 plants about one-third were constant in F_3 and two-thirds segregated again, a preponderant majority of their progeny being short and only a few of them tall, with occasional prostrate, very dwarf, giant, and intermediate plants. The tall F_2's segregated in F_3 intc a majority of tall, twining plants and a minority of short plants. Irregular F_3 progenies were also produced by the very tall, the very dwarf, and the intermediate F_2 plants.

In a later paper, von Tschermak (1912) presented additional data from another cross between a short common bean and a tall runner bean. F_1 plants were intermediate but nearer the tall parent than the short one. Of the F_2's, 35 were classed as short, 2 as intermediate, and 18 as tall. F_3's from F_2 short plants were, with the exception of one tall plant, all short. About four-fifths of these short F_3's were constant in F_4, but one-fifth of them produced both short and tall plants, 58 of the former to 4 of the latter. The tall F_2 plants produced in F_3 45 short, 23

intermediate, and 10 tall plants; and these intermediate and tall F_3 plants produced F_4 progenies that segregated into short, intermediate, and tall, the numbers from intermediate F_3's being 7:4:10 and from tall F_3's 100:42:16. Von Tschermak concluded that this behavior necessitated the assumption of several factors for the difference in height of the parents and suggested that the results might be further complicated by numerical inequality in the formation of gametes and zygotes.

Emerson (1904) gave an account of crosses between various "pole" and "bush" races of *Phaseolus vulgaris.* Of the 109 F_1 plants reported, all were pole beans. In F_2, 324 pole beans and 118 bush beans were recorded. So far as tested, all F_2 bush beans bred true in F_3 and later generations, some having been tested to F_7. Of the F_2 pole beans, some bred true and others produced both pole and bush beans, 270 pole to 75 bush. It was pointed out in connection with this account that pole beans commonly differ from bush beans in at least three respects. They are generally taller, tho some very small pole beans, it was noted, are not much taller than some of the larger bush beans. As a rule, pole beans twine readily about supports, while bush beans do not, but it was noted that bush beans show the same tendency when growing with unusual vigor. The one characteristic difference was said to be that pole beans continue growth somewhat indefinitely, while bush beans are virtually determinate in growth.

MATERIALS AND METHODS.

The studies reported in this paper have been limited to races of the common bean, *Phaseolus vulgaris.* A few crosses have been made between dwarf races of the common bean and tall races of *P. multiflorus,* but, both because the climate of Nebraska is unsuited to the growth of the latter species and because crosses between the two species are more or less sterile, it has been impossible to grow more than the F_1 generation of such crosses.

Several years ago a large number of races of beans were obtained from reliable seedsmen. Some of the early crosses were made with plants grown from this commercial seed, but practically all of the later work, including most of that reported here, has been done with plants that have been grown in pedigree cultures and guarded against cross-pollination by insects for from one to four generations previous to the time the crosses were made. In all cases, whether the plants used in crossing were grown directly from commercial seed or from seed of pedigreed cultures, selfed seed from the parent individuals has been planted along

with the crossed seed, so that, if the parents happened not to be homozygous in their more prominent characters, that fact could be determined from their progenies.

All plants, seeds of which have been planted, have been grown in an enclosure covered with fine meshed wire netting or under individual covers of very thin bunting, mosquito bar, or wire netting (Figs. 1-3), except plants grown in the greenhouse in midwinter when no bees are present. Individual plant covers are not satisfactory where height of plant is to be studied, since they can scarcely be made large enough not to interfere with

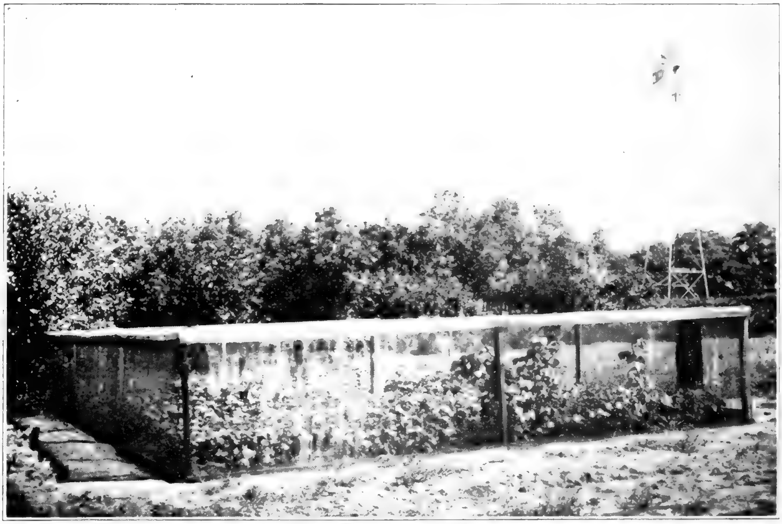

Fig. 1.—Enclosure of fine meshed wire netting used to prevent insect pollination.

normal growth. Moreover, individual wire covers are difficult to manage, mosquito bar is too easily torn, and cloth of even the very lightest grades increases the temperature under it to an injurious degree in this climate. The large wire-netting enclosure is therefore now used exclusively. While many insects, including species of very small bees, gain entrance to the enclosure readily, they apparently do not effect cross-pollination. Even when grown in the open garden, beans are not cross-pollinated so largely as might be expected from the number of large bees found visiting the flowers. There is, however, sufficient crossing to make results unreliable when the plants from which seed is saved for planting are grown in the open. I have observed

from 0-10 per cent of undoubted crosses in the progenies or pure races grown in the garden.

Crosses have invariably been made in the greenhouse during winter. The rather hot, dry weather of Nebraska makes it almost impossible to cross bean plants in the garden. The stamens are removed shortly before the flower bud is ready to open and pollen from another plant is applied at once. Occasionally an anther may be crushed in the process of emasculation and a grain of pollen thus comes into contact with the stigma of the same flower. Altho the stigma is always examined with the aid

Fig. 2.—Individual plant-covers of cheesecloth used to guard bush beans against insect pollination.

of a lens after the removal of the anthers, partial self-fertilization occasionally results. It almost never happens that the parent races are so nearly alike that such accidental fertilizations cannot be detected when the F_1 plants are grown. Among F_1 progenies, several plants apparently exactly like the maternal parent race have been tested thru two or three generations and in all cases have proved to be pure races. The records of all such plants occurring accidentally in F_1 progenies have been discarded in preparing the data for this paper.

When planted, the seed of a single individual plant or of the cross of two individuals is given a family number, which is entered on the record card and used on the stake label to mark

the family in the garden. The several plants of a family are also given individual numbers based upon their position in the row and when necessary are marked by means of individual stakes. The record card of a family bears, in addition to the family number, the family and individual numbers of the selfed parent plant or of the two parent plants crossed. Seeds of each individual plant are kept in a separate receptacle bearing the family and individual numbers. Records are entered on the family cards under individual numbers only. All planting and harvesting

Fig. 3.—Individual plant-covers of mosquito bar and cheesecloth used to protect pole beans from insect pollination.

of seeds concerned in this study have been done by the writer or by assistants under his supervision.

The records of habit of growth reported here have all been made by the writer, who has also made all counts of numbers of internodes and all measurements of internode lengths and plant heights. The internode counts and measurements were recorded in considerable part by Mr. E. R. Ewing, computer in genetic investigations. The writer is also indebted to Mr. Ewing for the calculation of most of the statistical constants used in this paper. Further assistance in checking these calculations has

been rendered by Mr. E. W. Lindstrom, graduate assistant in genetics at Cornell University.

GROWTH HABIT IN BEANS.

As was pointed out in an earlier paper (Emerson 1904), common beans are of two distinct types with respect to habit of growth. They are either *determinate* or *indeterminate*. The former are commonly called bush beans from the fact that they are as a rule comparatively short, erect, and much branched,

Fig. 4.—Upper part of an old bean plant of indeterminate growth, showing flower buds at the upper nodes and mature pods at lower nodes.

while the latter are termed pole beans from the supports commonly provided for them.

In pole beans, the first flower clusters appear in the axils of the leaves at some of the lower nodes, usually the fourth to the seventh. As the plants increase in height and new nodes are added, flowers continue to appear in regular order from the lower to the higher nodes. (See Fig. 5.) It is not uncommon to find fully ripe pods at the lower nodes and newly opened flowers or flower buds at the upper nodes of the same plant. (See Fig. 4.)

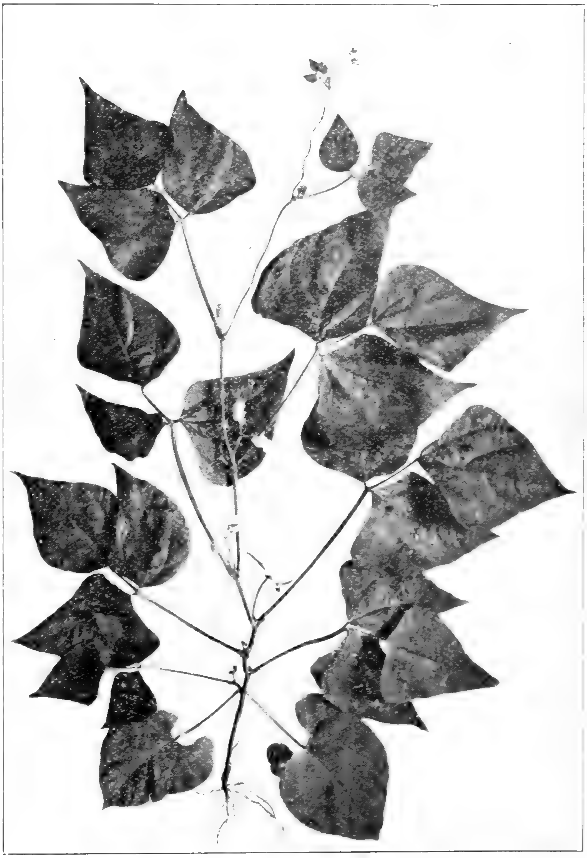

Fig. 5.—A young bean plant of indeterminate growth—pole bean—with newly formed pods at node 5, flowers at nodes 6 and 7, and flower buds at nodes 8-12.

Under ordinary conditions in the garden, it is true, pole beans do not continue to grow indefinitely, but termination of growth is apparently always due to unfavorable conditions of soil or weather such as low temperature, extreme dryness, etc., or to the exhaustion of the plants by heavy seed production. That this is true is shown by the fact that a race of small pole beans, which commonly ceases growth in the garden at a height of 1.0-1.5 meters with 15-20 nodes and perhaps dies long before the approach of cold weather, has been made to reach a height of 4 meters with 30 nodes when grown under the more favorable conditions of the greenhouse and when allowed to develop few

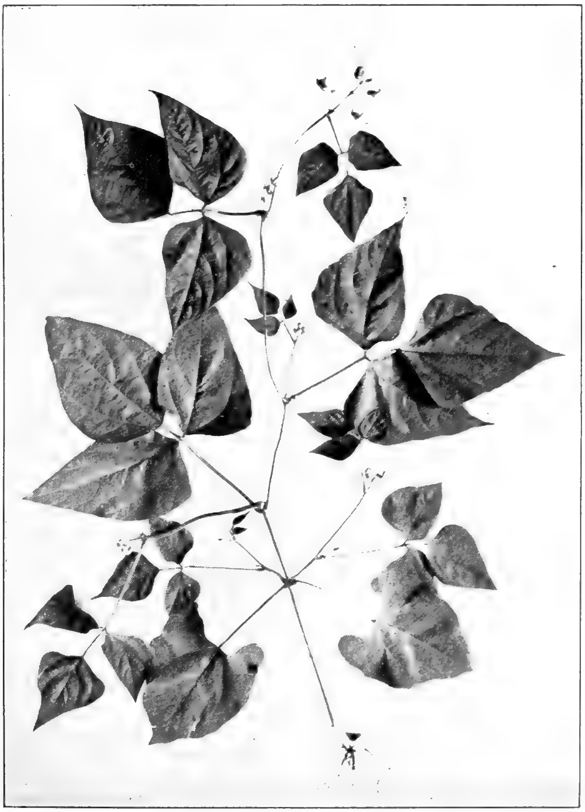

Fig. 6.—A young bean plant of determinate growth—bush bean—with a flower cluster terminating the axis at the sixth node.

pods. (See growth curves, Fig. 12.) Apparently growth would have continued longer in the greenhouse had not the experiment been discontinued. Under very favorable conditions, then, pole beans not only produce longer internodes but also more of them than under unfavorable conditions. The same indeterminate habit of growth is exhibited by all the branches of pole beans.

In bush beans, on the contrary, usually only from 4 to 8 nodes develop in the main axis. Rich, moist soil and favorable weather increase the internode length just as in pole beans but apparently have little influence on the number of nodes. The main axis always terminates in an inflorescence. The flowers of this terminal inflorescence open first and the flowers at lower nodes only slightly later. (See Fig. 6.) Most of the pods mature at about the same time under ordinary conditions. If there has been a heavy setting of pods, and if conditions are unfavorable, the plants usually die when the pods mature. If the flowers are removed as soon as they form and if the soil and weather conditions are favorable, the plants remain alive for a considerable time, but the main axis cannot be forced to elongate further. The new growth resulting from this treatment always consists of secondary branches, usually from the lower nodes, and these branches, like the primary axis, terminate in flower clusters and cannot then be forced into further growth. Tertiary branches have the same fate.

The terminal inflorescence of a bush bean is indeterminate in the sense that the lower flowers of the inflorescence open first and the upper ones last, but not in the sense that the inflorescence continues to elongate indefinitely. (See Fig. 7B.) The axis of the terminal inflorescence of bush beans develops apparently as a continuation of the main axis of the plant. In Figure 7A there are shown parts of the upper leaf and petiole of a bush bean together with the terminal inflorescence. In the axil of this leaf there developed a cluster of flowers, similar to the flower clusters that develop in the leaf axils of pole beans, as seen in Figure 7C. A little higher on the axis of this terminal inflorescence (Fig. 7A), is a second flower cluster, but here a small bract takes the place of a leaf. The same is true of the third flower cluster. The fourth cluster terminates the axis of the inflorescence abruptly. The inflorescence seen in Figure 7B developed a fifth flower cluster by which the axis was terminated. (The first flower cluster of this inflorescence, in the axil of the upper leaf, is not shown in the figure.) In certain races of bush beans, the terminal inflorescence consists of only two or three flower clusters, rarely of a single cluster in the axil of the upper leaf.

The bush form of Lima bean (*Phaseolus lunatus*) is known to

have arisen as a mutation from pole Limas (Bailey 1895) and, since bush Limas bear the same relation to pole Limas as bush forms of the common bean do to the common pole beans, it seems probable that the common bush bean is a mutation from the pole bean. If this is true, the terminal inflorescence of bush beans may be regarded as a direct modification of the main axis of pole beans in which the leaves are reduced to mere bracts and in which the axis does not elongate indefinitely. The order of development of the flowers in the terminal inflorescence of bush beans remains exactly like the order of development of the flower clusters along the main axis of pole beans.

In this connection, attention should be called to the fact that, while the axillary flower clusters of some pole beans usually consist of but two or three flowers, like the individual flower clusters of the terminal inflorescence of bush beans, many varieties of pole beans have an axillary inflorescence identical with the terminal inflorescence of bush beans rather than with the individual flower clusters of that inflorescence. Such a condition is shown in Figure 7D, where a small part of the main axis of the plant is seen at the right and parts of a leaf and petiole at the left. It is conceivable that bush beans arose from pole beans thru the failure of the main axis to develop beyond a certain node. In this case an axillary inflorescence of the pole bean would become the terminal inflorescence of the bush bean. On this supposition, however, one could hardly explain the presence of the flower cluster almost, if not quite, universally seen in the axil of the upper leaf of bush beans, as illustrated in Figure 7A.

Usually the uppermost leaf of bush beans, which is here regarded as marking the end of the plant axis proper and the beginning of the terminal inflorescence, is at least as large as any of the other leaves of the same plants. The plant axis maintains its thickness to the upper leaf and there changes abruptly to the more slender axis of the terminal inflorescence. Sometimes, however, tho this is a rare occurrence, the upper leaf is very small and may even consist of only a single leaflet. The internode just below such an ill-formed upper leaf is shorter and more slender than in ordinary plants, so that the transition from plant axis to terminal inflorescence is somewhat gradual.

Very rarely the axis of a distinctly pole-bean plant terminates abruptly in an inflorescence like that of a bush bean. The first plant of this sort to attract my attention was one of the small pole-bean race known as Snowflake. The plant was grown in a small pot of rather poor soil. When two months old, it had reached a height of 53 centimeters, formed 17 internodes, produced a fair crop of pods, and practically ceased growing. It was

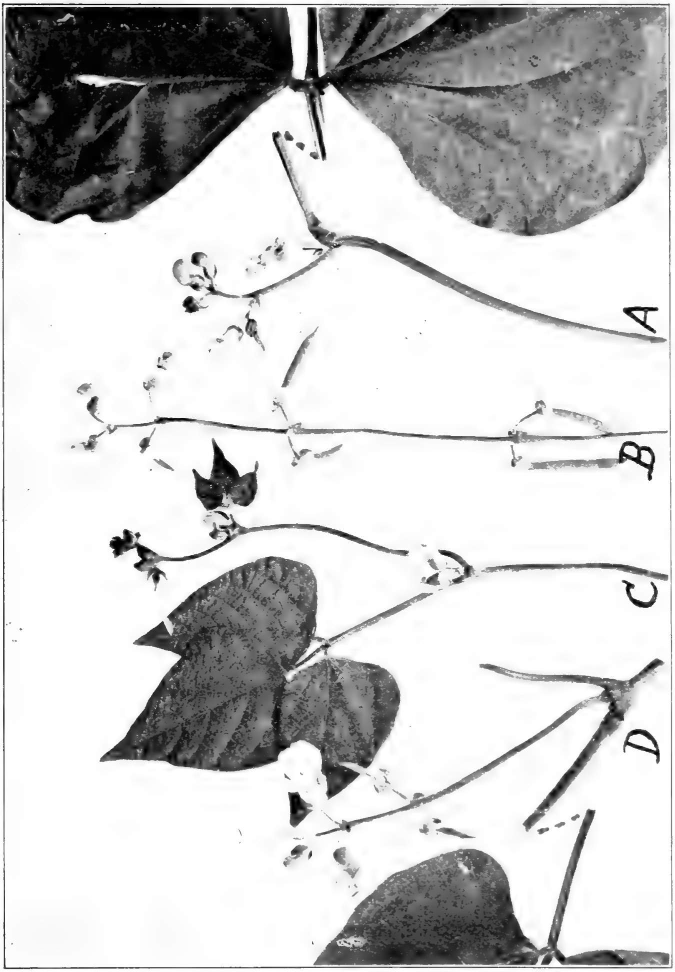

Fig. 7.—(A) Terminal inflorescence of a bush bean. (B) Same at a later stage. (C) Upper part of a pole bean stem with axillary flower clusters. (D) Axillary inflorescence of a pole bean.

a typical pole bean both in manner of growth and as regards the order of development of its pods. It was then transplanted to a large pot of rich soil and all its pods were removed. The plant responded promptly to this treatment by beginning growth anew. Both the main axis and the single side branch began again to elongate with gradually increasing rapidity. The side branch continued to grow for some time and to form pods after the manner of a true pole bean. The growth of the main axis, on the contrary, after only four new internodes had appeared, was abruptly terminated by an inflorescence exactly like the terminal inflorescence of bush beans.

Several other instances of this sort have since been observed. These plants, however, have all been grown under normal conditions, but have all occurred in the second generation of crosses of several bush-bean races with a single pole-bean race. These bush races have not given this result when crossed with other pole races and the pole race, in crosses of which these anomalous plants have occurred, has not itself been observed to show this peculiarity. Such behavior is not now understood but is being further investigated.

On the whole, it seems reasonable to suppose that the terminal inflorescence of bush beans is formed as a continuation of the plant axis and that it has developed thru a modification of the indeterminate axis of pole beans. This interpretation is supported both by the occasional appearance of ill-formed leaves as a transition from the plant axis proper to the axis of the terminal inflorescence of bush beans and by the rare occurrence of plants that are typical pole beans thruout the greater part of their length, but whose axis terminates in a bush-beanlike inflorescence. The individual flower clusters of the bush-bean inflorescence are, then, to be regarded as the homologues of the axillary flower clusters or inflorescences of pole beans. In place of the leaves of the pole-bean axis, there occur in the terminal inflorescence of bush beans only small bracts suggestive of adnate stipules.

In addition to determinate and indeterminate habits of growth, bush and pole beans differ in their ability to twine about supports. Circumnutation is strongly developed in all pole beans, but is not prominently exhibited ordinarily until after four or five internodes have developed, or until even later if the plants are growing slowly. Under ordinary conditions, bush beans rarely show prominent circumnutation, but, if forced into very vigorous growth, the long upper internodes develop pronounced circumnutation. (See Fig. 8.) Twining habit is, therefore, not a distinguishing characteristic of pole beans. Its absence from bush beans is incidental to the fact that their main axis is equivalent

Fig. 8.—A bush bean with the twining habit exhibited in the very long, upper—fifth—internode.

to the first four to eight internodes of pole beans, in which twining is little developed, particularly if growth is slow.

Bush beans usually have many branches and pole beans few branches, but this difference cannot be used to characterize definitely the two groups. When closely crowded together, bush beans often fail to develop branches. The shorter pole beans commonly have numerous branches and the taller kinds rarely fail to produce several branches. Degree of branching is in considerable part a varietal characteristic in both bush and pole beans.

Finally the bush and pole classes of beans differ in height. This naturally follows from the determinate and indeterminate

habits of growth of the two classes. Even the most vigorous bush bean cannot be expected ordinarily to reach a height, with its 4-8 internodes, that may ultimately be reached by even the smallest pole bean with its 15-20 internodes. If, however, length of particular internodes be taken as a measure of height, there is found in this respect no characteristic difference between the two classes of beans. Some races of bush beans have twice as long internodes as others and the same is true of distinct races of pole beans. Moreover, the internodes of some bush beans are

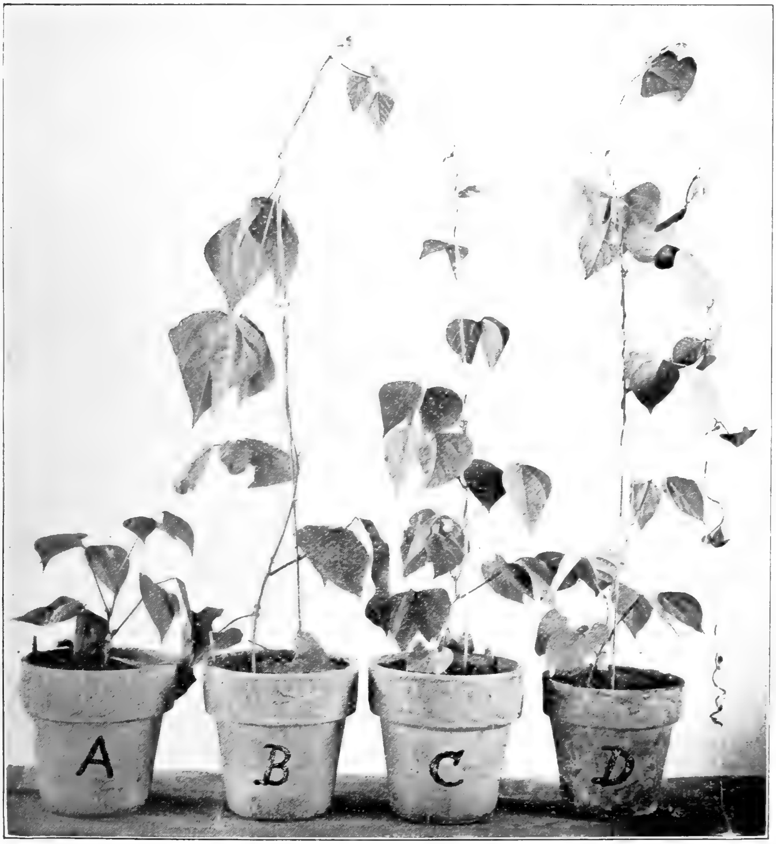

Fig. 9.—(A) Very short bush bean, Triumph. (B) Very tall bush bean, Tallbush, resulting from a cross between a tall pole bean and a short bush bean. (C) Short pole bean, Snowflake. (D) Tall pole bean, July.

so long and those of some pole beans so short that there is comparatively little difference in height between the two sorts. In fact, if the taller sorts of bush beans are forced by favorable soil, moisture, etc., and the shorter kinds of pole beans are retarded by unfavorable conditions, the bush beans will ordinarily exceed the pole beans in height. (Compare the plants shown in Fig. 9.) Internode lengths will be considered in detail in a later section of this paper.

GROWTH CURVES.

In all races of *Phaseolus vulgaris*, so far as I have observed, growth is fairly rapid at the start but soon slackens materially as the food stored in the cotyledons becomes exhausted and then becomes increasingly more rapid as the young plant becomes well established. In general, therefore, the hypocotyl is longer than the epicotyl, which, in turn, is longer than the second[1] inter-

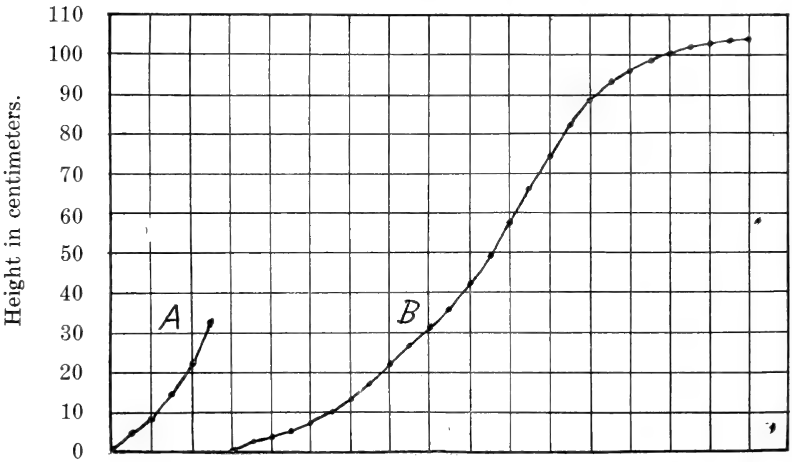

Fig. 10.—Growth curves of the main axis of (A) a medium tall bush bean, Red Marrow, 3,330 (1), and (B) a medium short pole bean, Snowflake, 3,425 (f). The dots, connected by lines to form these and all later growth curves, indicate the heights of mature plants at the upper end of the designated internodes.

[1] Since the hypocotyl of a growing or mature plant cannot readily be measured, the epicotyl has been measured as the first internode. Thruout this paper, the *first* internode is regarded as beginning at the point of attachment of the cotyledons, the *second* at that of the primary leaves, the *third* at that of the first trifoliate leaf, etc.

node. Usually, tho not universally, the third internode is longer than the second and occasionally, tho rarely, exceeds the first internode in length. In normal plants growing under fairly uniform conditions, internode length becomes increasingly greater from the third internode on until the maximum is reached.

In plants of determinate growth habit (bush beans), maximum internode length for the main axis sometimes occurs at the fourth and sometimes not until the seventh or eighth internode, but, whatever the number, it is almost universally the terminal internode that is longest (Fig. 10). This statement could not

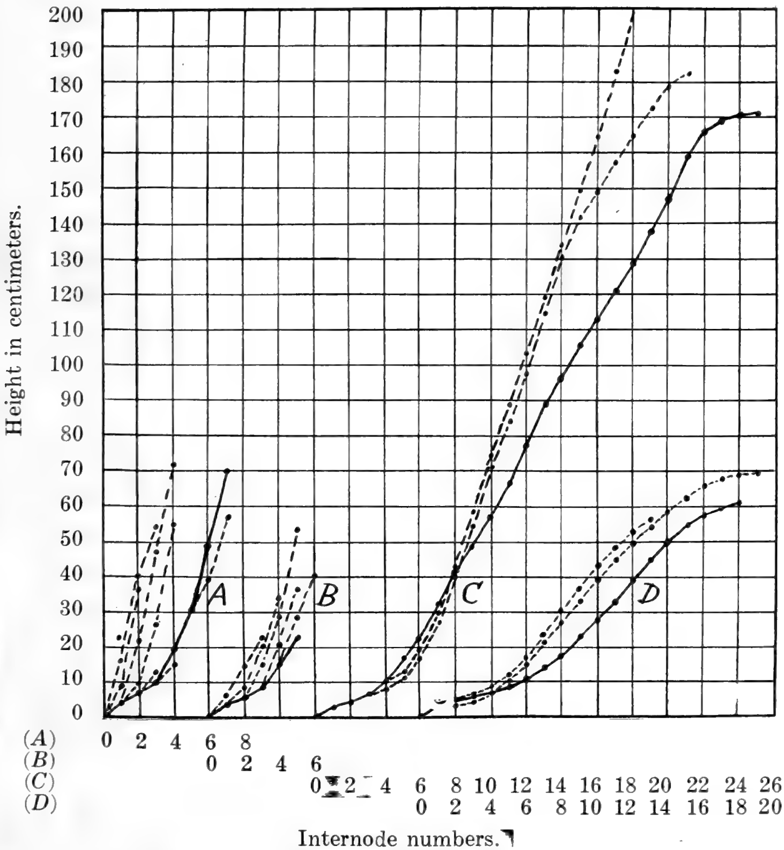

Fig. 11.—Growth curves of the main axis—solid lines—and of the branches—broken lines—of (A) a very tall bush bean, Tallbush, 3,420 (3), (B) a medium tall bush bean, Red Marrow, 3,459 (1), (C) a part of very tall pole bean, Fillbasket, 311 (4), (D) a very short pole bean, Snowflake, 231 (3).

hold if the internodes of the terminal inflorescence were included as a part of the plant axis, for they are shorter than the internodes immediately below them. The axis of the inflorescence is, however, so definitely differentiated from the plant axis proper that it is not included here in measurements of the latter.

In plants of indeterminate growth habit the internodes are of comparatively uniform length for some distance on both sides of the longest internode, but sooner or later they become shorter. This shortening of the internodes is slight at first and increasingly more marked as growth proceeds. The growth curve for this period of retardation is therefore practically the reverse of that for the period of acceleration (Fig. 10).

The larger branches of bean plants manifest in general peculiarities of growth very similar to those of the main axis. Such curves are shown in Figure 11. Branches are as a rule more vigorous than the plant axis. This is particularly true of bush beans where, as is shown in Figure 11A and 11B, even the first internode of the branches is commonly considerably longer than the corresponding internode of the plant axis. It is not uncommon for some of the branches of bush beans to reach twice the height of the plant axis. In Figure 11B is shown a bush bean of which the axis was 233 mm. high and a branch from the third node of the axis 535 mm. high. In pole beans, tho the branches are often somewhat more vigorous in growth than the plant axis, they are by no means universally so and very frequently grow less rapidly at the start than the corresponding part of the plant axis, as shown at C and D, Figure 11. It seems possible that the relative rapidity of growth of axis and branches may depend in part upon whether the branches start during the period of general growth acceleration or retardation and it certainly depends in part upon the weather.

Acceleration of growth in the young plant is probably due to the fact that the plant is then constantly becoming better established. Its roots are gradually becoming better able to obtain water from the soil and its rapidly enlarging leaf area is continually becoming better able to supply food materials for growth. But why should not this acceleration in rate of growth continue indefinitely in plants of indeterminate habit? Above all why should retardation in growth rate occur? It is unlikely that senility is to be considered in this connection. The heavy drain put upon the plant's resources by the development of a crop of pods and seeds doubtless has much to do with retardation of growth rate. This is particularly true of the smaller pole beans, which early set a heavy crop of pods. With the larger and later pole beans, the less favorable weather late in the season doubtless has a pronounced influence in retarding growth.

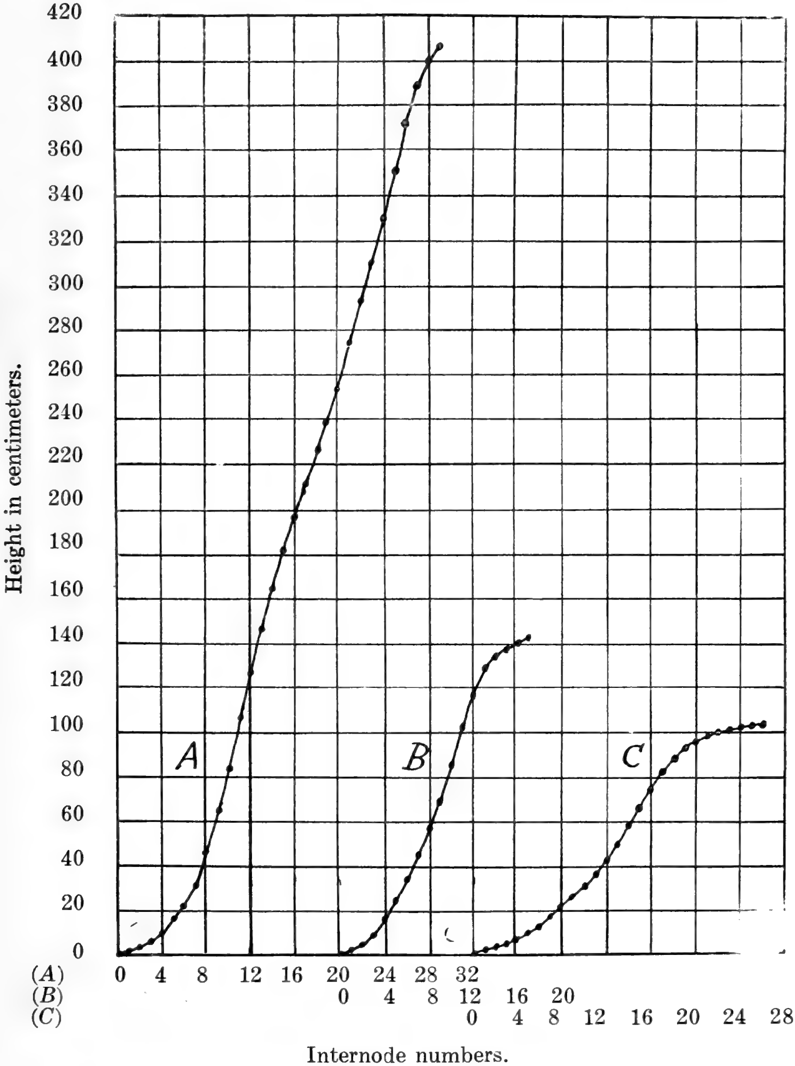

Fig. 12.—Growth curves of the small pole bean Snowflake. (A) Plant 2,424 (B) grown in a large pot of rich, moist soil in the greenhouse and only a few pods permitted to develop. (B) Plant 2,424 (F) grown in a small pot of poor soil in the greenhouse and allowed to mature its full crop of seeds. (C) Plant 3,425 (f) grown in the garden during a rather hot, dry summer and allowed to mature a heavy crop of seeds.

When heavy seed production is prevented and when temperature, moisture, etc., are kept fairly uniform, retardation of growth can be avoided for a long time, if not indefinitely. In Figure 12 are shown growth curves of three plants of the same inbred strain of a race of very small pole beans, Snowflake (Navy or Pea bean). A and B were from seeds of the same selfed plant and C was directly related to them. Under the somewhat unfavorable conditions in the garden during a hot and rather dry summer (Fig. 12C), growth was at no time very rapid. The heavy setting of pods and increasingly unfavorable weather caused a marked retardation of growth at about the twentieth node and at the height of about 1 meter. With the more favorable temperature and humidity and somewhat deficient light of the greenhouse (Fig. 12B), growth was rapid at first but the development of a considerable crop of pods and the deficiencies of the soil—about 1.5 liters of a poor sandy loam—brought about an early retardation of growth at about the fifteenth node and at a height of 1.5 meter. Under the same favorable atmospheric conditions, with the advantage of abundant soil fertility—about 10 liters of rich loam—and without the drain of heavy pod production, a sister plant (Fig. 12A) kept up a remarkably uniform growth to near the thirtieth node and to a height of four meters when the experiment was discontinued.

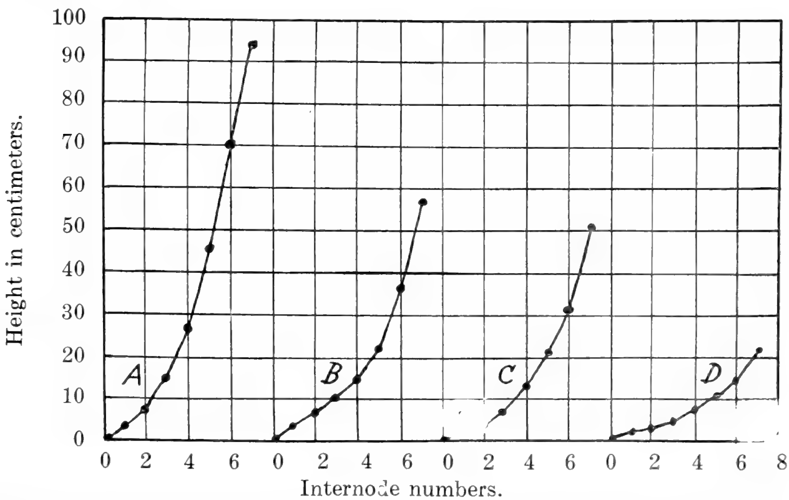

Fig. 13.—Growth curves of (A) and (B) medium tall bush beans, Red Marrow, 2,423 (B) and 2,423 (F), and of (C) and (D) short bush beans, Triumph, 2,422 (A) and 2,422 (F). Plants (A) and (C) were grown in large pots of rich soil and plants (B) and (D) in small pots of poor soil.

Bush beans are, of course, influenced by unfavorable weather and soil conditions as well as pole beans but no retardation in rate of growth of the upper internodes comparable to that in pole beans is to be seen. The acceleration in rate of growth is lessened but the termination of growth is no more abrupt under unfavorable than under favorable conditions. Figure 13 shows characteristic growth curves of bush beans when grown in rich and in poor soil under favorable atmospheric conditions. These plants (Fig. 13 A, B, C, D) were grown at the same time and under the same conditions as two of the plants just discussed

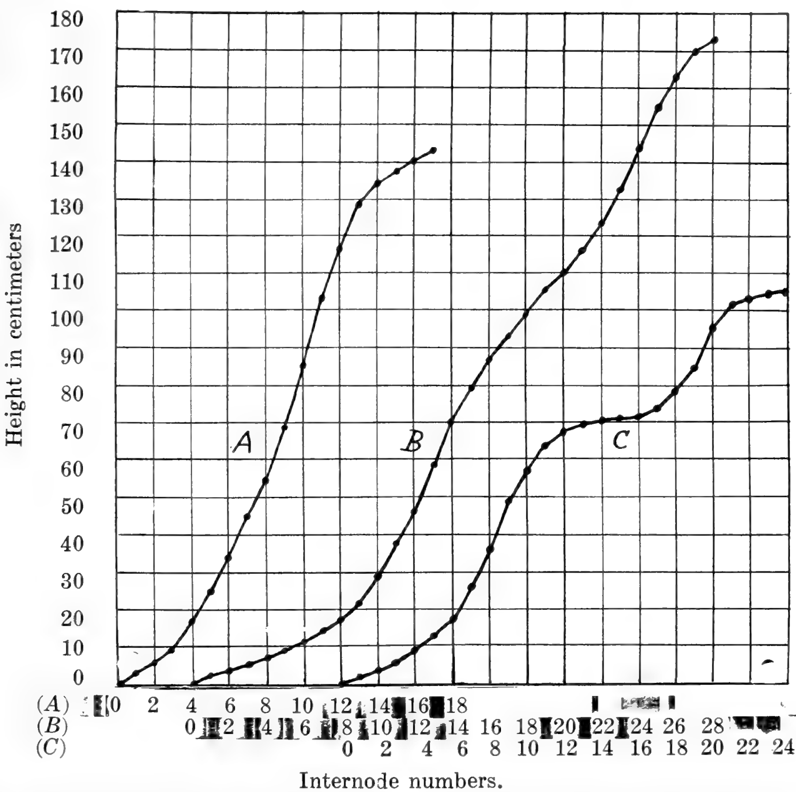

Fig. 14.—Growth curves of pole beans. (A) Snowflake 2,424 (F) grown under fairly favorable and comparatively uniform conditions in the greenhouse. (B) Snowflake 3,427 (f) grown in the garden in a dry summer and irrigated twice. (C) July 3,956 ($_7$) grown in the greenhouse under alternately favorable and unfavorable conditions.

(Fig. 12A, B), A and C in large pots of rich soil and B and D in pots of poor soil. Plants A and B belong to a race of rather tall bush beans, Red Marrow, and plants C and D to a race of very short bush beans, Triumph. Plants A and B were from seed of the same self-pollinated plant of a previously inbred strain as were also plants C and D.

That retardation in rate of growth in pole beans is often due to unfavorable, and acceleration to favorable, weather or soil conditions is seen in the behavior of plants grown in the garden during the dry summer of 1912 and irrigated twice. Figure 14B contrasts the irregularity in growth of such a plant with the regularity in growth of a plant (Fig. 14A) kept under the comparatively uniform conditions of the greenhouse. Both plants belonged to the same inbred strain of the rather short pole bean, Snowflake.

The extreme irregularity of growth of the plant shown in Figure 14C was induced by alternately favorable and unfavorable conditions. This plant was one of a rather tall race of pole beans, July, and was grown in the greenhouse. It was started in a rather small pot of rich soil and its growth forced by favorable temperature and abundant water. Water was then withheld until it wilted badly, and for some time it was given only sufficient water to keep it alive. When its growth had almost ceased, it was transferred to a large pot of rich soil and again kept well watered. Under these conditions its main axis elongated rapidly until checked by a second period of artificial drouth.

INHERITANCE OF DETERMINATE AND INDETERMINATE HABITS OF GROWTH.

The results of Mendel (1865), von Tschermak (1904 and 1912), and of the writer (1904) were reviewed earlier in this paper. Mendel described his results in terms of height, but from my own work I am convinced that the character pair with which he dealt was really determinate and indeterminate habits of growth. Von Tschermak also designated his plants merely as tall and short. While it is possible that the very irregular results secured by him are due to the fact that he dealt with a cross of very distinct species, *Phaseolus vulgaris* and *P. multiflorus,* it seems quite as probable that they are due to failure to disti guish sharply between habit of growth and other factors of height.

The classification used in my earlier paper (1904) was based distinctly upon habit of growth, tho the classes were not there listed as determinate and indeterminate. The data then presented indicated clearly the perfect dominance of the indeterminate

growth habit, the definite segregation in F_2 into indeterminate and determinate habit with a ratio approaching 3:1, and the typical Mendelian behavior in F_3 and later generations of both the dominant and recessive characters. Since the publication of that paper, a large number of crosses between pole and bush beans have been grown, but, since these crosses were made primarily for the study of other characters, definite records of habit of growth for F_2 have been made in only a comparatively few cases.

Including the records reported in my former paper, I have grown in all 948 F_1 plants of crosses between pole and bush beans. Without exception these have been all indeterminate in habit of growth.[1] As parents of these crosses there have been employed 101 distinct races or strains, 58 of which were bush beans and 43 pole beans. Of the rather large number of F_1 plants, progenies of which have been grown, positive records are available of the offspring of only 32 plants of 16 distinct crosses. From these there were produced in F_2 1,104 plants, of which 832 were indeterminate and 272 determinate in growth, a ratio of 3.01:0.99, a variation from expectation well within the probable error for the numbers observed. Of the many F_2 bush plants tested in F_3, accurate records of only 23 are available. All of these were found to be constant for determinate growth habit, having produced 588 bush and no pole beans in F_3. Likewise 24 F_2 pole beans are known to have bred true, having produced 686 pole and no bush beans in F_3. Again 40 F_2 pole beans segregated into pole and bush beans in F_3. The F_3 progenies of these heterozygous F_2 pole beans totaled 1,259 plants. In most of these cases, however, my notes indicate merely the fact of segregation without exact records of the number of plants of the two classes.

It can be said then, by way of conclusion, that in *Phaseolus vulgaris* indeterminate and determinate habits of growth constitute a simple Mendelian character pair with indeterminate habit completely dominant.

INHERITANCE OF NUMBER OF INTERNODES.

While it is obviously true that habit of growth is an important factor in determining ultimate height in bean plants, it is one of the few size factors that can be definitely recognized and that can, therefore, be given separate treatment. In many crosses the parents of which differ greatly in height, growth habit can

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[1] Since these records are merely confirmatory of the results previously reported in detail (Emerson 1904), it is thought sufficient to give only the summaries here.

be disregarded since the same habit is common to both parents. It has, therefore, seemed wise to consider growth habit as something entirely apart from the other factors for height. This procedure greatly simplifies our problem—a fact that does not seem to have been recognized by some investigators. Up to this point we have been concerned largely with habit of growth. We come now to a consideration of other factors affecting height.

Number of internodes plays perhaps an equal part with internode length in determining height of plants. It is a character that is obviously very closely related to habit of growth. Plants of determinate growth habit have a rather definite number of internodes, while those of indeterminate growth habit may have from comparatively few to very many internodes. It is true that certain races of bush beans show rather constant differences in number of internodes, but the fluctuation within a particular race—2-4 internodes—is greater than the average difference between the most diverse strains that have come under my observation. Some races of pole beans also commonly have more internodes than others, but number of internodes is here so greatly influenced by the weather and other external conditions that its investigation is beset with many difficulties. Under the comparatively uniform conditions that can be maintained in a greenhouse the difficulties are lessened, but it has been impossible for me to make use of sufficient greenhouse room for studies of this sort. Not the least difficulty met, in carrying out an investigation of this kind in the garden, has been the breaking of the main axis of tall plants by winds. The taller pole beans, moreover, become so badly tangled that it is extremely difficult to make accurate counts. Some observations of number of nodes have been made, however, and they are presented here with a full realization of their unsatisfactory nature.

The races used in these crosses were: Red Marrow, a tall bush bean; Triumph, a short bush bean; July, a tall pole bean; and Snowflake, a short pole bean. The two races of bush beans were chosen for crossing on account of the great difference in their height. This difference, it is true, is largely one of internode length, but the number of internodes of these races is of interest for comparison with the bush beans occurring in F_2 of bush-pole crosses.

In Table 1 are shown the variations in number of nodes of the two bush races, of the F_1 and F_2 generations of crosses between them, and of the bush plants that occurred in F_2 of crosses between these bush races and the pole races July and Snowflake. All these plants were grown in the garden in 1912. The plants representing the parent races were directly descended from the

individual plants used in making the crosses. Owing to the small number of plants in any one progeny, progenies of like breeding were lumped together in making up the arrays.

In mean number of internodes Red Marrow and Triumph differed by only 0.20 ± 0.06 of an internode, or about three times the probable error of the difference. The means for the F_1 and F_2 generations were almost exactly half way between the means of the parents. It is possible that the two parent races are not inherently different but that the slight difference observed in mean number of internodes was a mere matter of chance. The same would then apply to the intermediate number of internodes of F_1 and F_2. The number of F_1 individuals was so small that the determination of the mean for plants of that generation has little value. It should also be noted that the difference between the mean number of internodes for F_2 and that for either parent lot was less than twice the probable errors of these differences. The variation in internode number as measured by the coefficient of variation was somewhat greater in F_2 than in either parent. The differences, however, are only from two to three times their probable errors. The most that can be said, therefore, is that, if this difference between the parents and the F_2 generation has any significance, it is that there is a slight inherent difference between the parents and that the somewhat increased variability in F_2 indicates segregation of the factors that differentiate the parents.[1]

The bush bean segregates in F_2 of the crosses between Triumph and July and between Triumph and Snowflake exhibited about the same intensity of variation as the F_2 plants of the cross between Triumph and Red Marrow. The variation was somewhat greater in case of the F_2 bush segregates of the cross between Red Marrow and July, the coefficient of variation being 13.98 ± 1.69 per cent. While this is greater than that of Red Marrow, which was 10.76 ± 0.57 per cent, it is less than that of July (see Table 2), which was 15.61 ± 1.42 per cent. Considered in connection with their probable errors, the differences—3.22 ± 1.78 and 1.63 ± 2.21 respectively—cannot be considered significant. It cannot therefore be told, without further breeding tests, whether the variation exhibited by these F_2 bush plants was due to segregation of factors influencing internode number. It seems possible, however, that a race of indeterminate growth

[1] Here and consistently elsewhere in this paper the facts are interpreted in terms of the multiple-factor hypothesis solely because that hypothesis seems to the writer to afford the simplest adequate interpretation. He desires, however, to disavow any dogmatic notions as to the truth of this or any other hypothesis. A discussion of the matter appears later in this paper.

habit, like July, would be subject to greater variation than plants of determinate growth. If this is true, the variation shown by the F_2 bush plants of the cross between Red Marrow and July should be compared with that of the bush-bean parent, Red Marrow, rather than with the pole-bean parent, July. Such a comparison suggests the probability that the parents of this cross may have differed by one or more factors for number of internodes and that these factors segregated in F_2.

Whether or not the variation noted in the F_2 bush plants of the crosses discussed above indicates segregation of factors for number of internodes, there is less doubt in case of the cross between Red Marrow and Snowflake. The coefficient of variation of the F_2 bush beans of this cross was 19.65 ± 2.18 per cent as against only 10.76 ± 0.57 for Red Marrow, a difference of 8.89 ± 2.25. The genetic factors for number of internodes, in regard to which the parents of this cross presumably differed, must be distinct from the factor or factors concerned with habit of growth, for all these F_2 bush plants must have lacked the factor for indeterminate growth and all must have had the factor for determinate growth. If this is true, the F_2 pole-bean segregates of this same cross should also have shown greater variation than the parents. By reference to Table 2, it will be seen that this was actually the case.

In Table 2 are given the frequency distributions for number of internodes of the pole-bean parents of some of the crosses discussed above, of the F_1 generation of these crosses, and of the F_2 segregates of indeterminate growth habit. The plants from which these records were made were all grown side by side in the garden in 1912. Owing to the small numbers of plants in individual families, the several families of each race and of one generation of each cross are thrown together, just as was done in Table 1. While it is recognized that this procedure is somewhat questionable, it is believed that the results are not vitiated materially thereby.

The rather short pole bean, Snowflake, owes its low stature in part to a comparatively small number of internodes. The mean number of internodes was a little over 20. The much taller race, July, averaged somewhat over seven internodes more. The greater vigor of the F_1 generation of the cross of these races resulted in an average of a little over 30 internodes. The F_1 progenies of the crosses between the tall bush bean, Red Marrow, and these pole beans had slightly fewer internodes than July but considerably more than Snowflake. The F_1 plants of the cross between the very short bush bean, Triumph, and the comparatively short pole bean, Snowflake, were among the most

vigorous of all the plants grown in 1912. Tho both the parents are among the earliest races of beans, the F_1 plants of the cross were later in flowering and in ripening seeds than any of the other crosses considered here. The same peculiarity was observed in F_1 plants of this cross as grown near Boston, Massachusetts, in 1911. The large mean number of internodes, over 31, shown by the F_1 plants of this cross is probably due directly to the vigor of growth and lateness induced by heterozygosis. This is indicated by the fact that in F_2 very few plants had as many internodes as the mean of F_1. The F_2 plants of the cross between Snowflake and Red Marrow had practically the same mean number of internodes as did the F_1 plants.

Unfortunately no records are available of the number of internodes in F_2 of the cross between the two pole beans, Snowflake and July, or of the crosses between July and the bush races Triumph and Red Marrow. The variation shown in F_1 of the cross between Snowflake and July was slightly less than that exhibited by the parent races, but the differences are too small to be significant. In F_1 of the Snowflake-Triumph, Snowflake-Red Marrow, and July-Red Marrow crosses, the variation was less than in the pole-bean parents but somewhat greater than in the bush-bean parents (Table 1). The small number of plants grown in F_1 families may have been in part responsible for this comparatively small variation. In F_2 the variation in the crosses between Snowflake and these bush races, as measured by the coefficient of variation, was greater than in even the pole-bean parent and much greater than in the F_1 plants. In F_2 of the Snowflake-Red Marrow cross, the coefficient of variation was only 3.81 ± 2.08 greater than that of Snowflake but 9.51 ± 1.44 greater than that of Red Marrow. The coefficients of variation for Red Marrow, Snowflake, the F_1 generation of the cross between them, and the F_2 pole-bean segregates of the cross were respectively 10.76 ± 0.57, 16.46 ± 1.61, 10.73 ± 1.29, and 20.27 ± 1.32 per cent. It will be recalled that the F_2 bush segregates of this same cross also showed considerable variation in number of internodes (Table 1), the coefficient of variation being 19.65 ± 2.18 per cent. The standard deviations are widely different for these lots, but standard deviation is not a good measure of variation for comparisons between plants so unlike as pole and bush beans.

The full significance of the greater variation in the F_2 generation than in F_1 or in the parents, as presented in Tables 1 and 2, and discussed above, is appreciated only when it is realized that the coefficients were determined for the pole and bush segregates separately. If the whole F_2 generation of either cross between

pole and bush beans be thrown into one array, the variation is markedly increased. The array for the Snowflake-Triumph cross arranged in three-internode classes extends from 5 to 32 internodes and the frequency distribution is:

11—2—0—0—3—8—8—4—2—3.

The statistical constants are:

Mean—17.66 ± 0.96 internodes.
Standard deviation—9.07 ± 0.68 internodes.
Coefficient of variation—51.34 ± 4.72 per cent.

Similarly the frequency distribution for the whole F_2 of the Snowflake-Red Marrow cross, in three-internode classes from 5 to 44 internodes is:

16—4—0—0—3—6—12—19—9—2—4—2—0—1.

The statistical constants are:

Mean 21.00 ± 0.78 internodes.
Standard deviation 10.16 ± 0.55 internodes.
Coefficient of variation 48.38 ± 3.19 per cent.

The very large coefficients of variation shown by these F_2 families, about 50 per cent, as compared with the much smaller coefficients for the parents and F_1, from about 10 to 17 per cent, are plainly an expression of the F_2 segregation in habit of growth. Indeterminate habit necessarily carries with it the ability to produce many internodes, while determinate growth makes impossible the development of more than a few internodes. But it has been shown that distinct races of pole beans, both equally indeterminate in growth, differ noticeably in the number of internodes they ultimately produce. Is it not possible then that a tendency to produce a large number of internodes, say 30 to 40, might be inherited from a bush bean, which, owing to its determinate habit of growth, is itself unable to develop more than a few internodes? Likewise is it not possible that a tendency to produce a few internodes may also be inherited independently of habit of growth?

These questions, if I have correctly interpreted my data, are given an affirmative answer by the results of the cross between Snowflake and Red Marrow. Snowflake showed a range of 12 internodes (14-26) and a mean of 20.48 ± 0.44. The F_1 plants had a range of 12 internodes (20-32) with a mean of 26.56 ± 0.48. The mean for the F_2 pole-bean segregates was 26.31 ± 0.47, very nearly the same as in F_1, but the range was 27 internodes (17-44). Red Marrow had a range of 3 internodes (4-7) and a mean of 5.78 ± 0.05. The F_2 bush segregates of the cross between it and Snowflake had a smaller mean, 5.45 ± 0.16. The range of variation was the same as for Red Marrow, but the distribution was not that of normal fluctuation. While no new values not seen in

Red Marrow were found in the F_2 plants, the relatively large number of plants with the extreme numbers of internodes, 4 and 7, suggests that it would be possible to isolate distinct types of bush beans in F_3 from this F_2 lot. Only by further breeding tests can it be told whether this suggestion is correct. The F_3 generation of this cross has not been grown, but fortunately I have partial records of another cross which afford direct evidence of the production of diverse types of bush beans from a cross between bush and pole races. The cross is one between Longfellow and Fillbasket.

Longfellow is a rather short bush bean and Fillbasket is a medium tall pole bean. Counts of 10 to 20 plants each when grown under similar conditions in the garden in 1909 (except F_2, which was grown in the greenhouse) gave ranges of variation and means as follows:

	Internode numbers Mean	Range
Fillbasket	17.3	14-22 = 8
Fillbasket-Longfellow, F_1	21.4	18-24 = 6
Fillbasket-Longfellow, F_2 pole	20.8	13-26 = 13
Fillbasket-Longfellow, F_2 bush	6.2	4- 8 = 4
Longfellow	5.3	4- 6 = 2

From two F_2 bush plants with 6 and 7 internodes respectively, two small F_3 families were grown in 1910 each showing about the same range of variation as that of F_2. In 1911 near Boston, Massachusetts, were grown several F_4 families of this cross. One of these (Family 3,254) was from a bush plant with 6 internodes which was of the F_3 lot descended from the 6-internode F_2 plant. The other lot (3,251) was from a bush plant with 7 internodes of the F_3 progeny of the 7-internode F_2 plant. In the same garden and very near these F_4 families, were grown several families of Longfellow. All of these were descended directly from the individual plant of Longfellow used in making the cross with Fillbasket now under discussion, but were four generations removed from that plant and therefore were its great-great-grandchildren. The several families of Longfellow showed only slight differences in height of plants. One of them (3,247) was examined for number of internodes. The results are given in Table 3.

One of the F_4 families of the Longfellow-Fillbasket cross was very similar to the family of Longfellow of which internode counts were made, the means for number of internodes being 5.17 ± 0.06 and 4.94 ± 0.08 respectively, a difference of only 0.23 ± 0.10. The other F_4 family, however, had a mean number of internodes of 6.44 ± 0.08, which is 1.27 ± 0.10 more than the first F_4 family had. The variation of the three lots, as indicated by the coefficient of variation, was so small and so nearly the same for

all lots that it seems reasonable to conclude that the two F_4 families were breeding essentially true to distinct types with respect to number of internodes. It seems clearly evident from these results that a tendency to develop a comparatively large number of internodes, as bush beans go, was inherited in a bush-bean family from the pole-bean parent of a cross with a bush bean of comparatively few internodes.

It may be concluded, then, in so far as any conclusion can be drawn from the somewhat unsatisfactory records here presented, that genetic factors concerned in the determination of number of internodes in bean plants are distinct from factors for habit of growth and are inherited independently of them, so that, with respect to number of internodes, it is possible, from a cross between a pure strain of bush beans and a pure strain of pole beans, to isolate types of both bush and pole beans with other internode numbers than those of the parent races. The bearing that this may have upon the possible modifications of genetic factors thru crossing will be discussed in a later section of this paper.

CALCULATION OF INTERNODE LENGTH.

Habit of growth—determinate or indeterminate—has an influence upon the average internode length of a plant as well as upon the number of internodes. It is obvious that a bush bean, in which growth of the main axis is terminated when the period of acceleration in rate of growth has barely begun, cannot have so great an average internode length as a pole bean, in which growth-rate acceleration has continued thru a long period. For instance, a race of the tallest bush beans that have ever come to my notice had a mean internode length for the first six internodes of the main axis of only about 37 mm. as grown in 1912, while the shortest pole bean with which I am acquainted, when grown under similar conditions, had a mean internode length of about 48 mm. for the first 15 internodes. The mean length of the first 6 internodes of these same pole-bean plants was, however, only about 33 mm. Obviously this large bush bean has an inherent tendency to produce longer internodes than the small pole bean, but it cannot do so because its growth is terminated at an early stage of development. That such a tendency to produce long internodes is a characteristic of the tall bush bean is indicated by the F_1 progeny of a cross between it and the small pole bean. The mean internode length of the cross was about 34 mm. for the first 6 internodes and about 86 mm. for the first 15 internodes. The latter is 1.8 times the mean length of the first 15 internodes of the pole-bean parent.

Evidently the tall bush bean not only possessed potentially the character of long internodes but was able to impress that character upon its F_1 progeny when crossed with a pole bean, whereby the partially inhibitory action of determinate growth was removed.

It is plain from this that we cannot compare the average length of the few internodes of bush beans with that of the many internodes of pole beans. In order, therefore, that pole and bush beans may be directly compared, it is necessary to limit consideration to a definite number of internodes common to both types. All of the bush-bean races and crosses included in this study had a mean number of internodes between five and six. Since, if the comparison were between the first six internodes, a considerable number of bush plants would have to be discarded, only the first five internodes are here considered. For this comparison all internodes above the fifth in both pole and bush plants have been disregarded and all bush plants with less than five internodes have been discarded.

Even when consideration is limited thus to a definite small number of internodes, direct comparisons are not entirely trustworthy. For instance, July is a pole bean of vigorous growth and therefore of relatively long internodes, while Snowflake is a slow growing pole bean and consequently has comparatively short internodes, but the mean length of the first three internodes of Snowflake is greater than that of the corresponding internodes of July. Thus for 78 plants of Snowflake and 83 plants of July, grown side by side in the garden in 1912, the mean lengths in millimeters of the individual internodes from 1 to 15 inclusive were:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
July	19	14	23	41	56	78	115	122	120	120	134	140	139	138	135
Snowflake	26	17	20	24	25	28	38	45	53	62	73	82	84	77	63

The mean internode lengths in millimeters of these same plants as calculated at the end of any internode from 1 to 15 were, therefore, approximately:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
July	19	17	19	24	31	39	49	58	65	71	77	82	86	90	93
Snowflake	26	22	21	22	22	23	25	28	31	34	37	41	44	47	48
Difference	–7	–5	–2	2	9	16	24	30	34	37	40	41	42	43	45

The difference between these two races in mean internode length is thus seen to change rapidly up to about the eighth internode and much less rapidly from there on. This is indicated even more clearly by means of the ratios of the internode lengths of the two races as calculated at the end of each internode from 1 to 15.

Such ratios, with the mean internode lengths of July taken as 100, are:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Ratio 100:	137	129	111	92	71	59	51	48	48	48	48	50	51	52	52

The mean internode length of Snowflake is, then, approximately 50 per cent of that of July, if internode length be determined at the end of any internode from the seventh to the fifteenth. Obviously a comparison between these races in respect to internode length is unreliable if internode length is determined at the end of any internode before the seventh. But, if either of them is to be compared at all with any bush bean, the comparison must relate to the first five or six internodes.

The illustration used above is an extreme one. The difficulty in comparing pole and bush beans is not generally so great. Other examples will make this plain. It has been shown above that Snowflake is a small pole bean with a mean internode length of about 50 per cent that of the tall pole bean, July. Triumph is a very short bush bean and Red Marrow a rather tall one. Let us compare the mean internode lengths of 79 plants of Triumph and 73 plants of Red Marrow with those of Snowflake and July as given above. The comparisons to the end of the fifth internode are:

Internode No	**1**	**2**	**3**	**4**	**5**
Snowflake	26	22	21	22	22
Triumph	14	11	11	12	14
Ratio 100:	54	50	52	55	64

Internode No	**1**	**2**	**3**	**4**	**5**
Red Marrow	25	21	20	22	24
Snowflake	26	22	21	22	22
Ratio 100:	104	105	105	100	92

Internode No	**1**	**2**	**3**	**4**	**5**
July	19	17	19	24	31
Triumph	14	11	11	12	14
Ratio 100:	74	65	58	50	45

Internode No	**1**	**2**	**3**	**4**	**5**
July	19	17	19	24	31
Red Marrow	25	21	20	22	24
Ratio 100:	132	124	105	83	77

Internode No	**1**	**2**	**3**	**4**	**5**
Red Marrow	25	21	20	22	24
Triumph	14	11	11	12	14
Ratio 100:	56	52	55	55	58

From the comparison with Snowflake, it might at first seem that the internode length of Triumph is about one-half of that of Snowflake and the internode length of Red Marrow nearly equal

to that of Snowflake. The fact, however, that the mean-length ratio for Snowflake and Triumph is considerably greater for five internodes than for four, suggests that it might be still greater if it were possible to determine it for a greater number of internodes. The only conclusion that can be drawn from the comparison is the rather indefinite one that the potential internode length of Triumph is less than that of Snowflake, but probably not so much less as is indicated by the mean-length ratio for the first five internodes, 100:64. By similar reasoning it is concluded that Red Marrow has a potential internode length greater than that of Snowflake, the difference probably being more than is indicated by the mean-length ratio for the first five internodes, 100:92. Likewise, it may be said that the potential internode length of Triumph is considerably less and that of Red Marrow somewhat less than that of July. The direct comparison between Red Marrow and Triumph would appear reliable, for the reason that mean-length ratios are not far different when the comparison is made at the end of any internode from the first to the fifth. There is, however, a gradual increase in the ratio after the first internode. It would seem safe, therefore, to conclude that the potential internode length of Triumph is considerably less than that of Red Marrow but that the difference is probably not quite so great as is indicated by the mean-length ratio for the first five internodes, 100:58.

The only method available for accurately testing the potential internode length of bush beans is to cross them with pole beans and compare the internode length of the indeterminately growing plants thus produced with that of the pole-bean parent. For such a comparison the F_2 generation of the cross is to be preferred to the F_1 generation, because increased vigor due to heterozygosis is less in F_2 than in F_1. There is an additional reason for this preference in case of beans. The difficulty in cross-pollinating bean flowers and the fact that only a few seeds are obtained from any one pollination, make it next to impossible to grow even moderately large numbers of F_1 plants. Comparisons of the F_2 generation of Triumph-Snowflake (56 plants), Red Marrow-Snowflake (74 plants), and July-Snowflake (78 plants), with each other and with Snowflake, are given here:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Snowflake	26	22	21	22	22	23	25	28	31	34	37	41	44	47	48
Triumph-Snowflake	21	18	19	20	21	23	25	28	31	33	35	37	38	39	39
Ratio 100:	81	82	90	91	95	100	100	100	100	97	95	90	86	83	81

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Red Marrow-Snowflake	25	22	23	26	28	30	34	38	42	45	48	51	54	55	56
Snowflake	26	22	21	22	22	23	25	28	31	34	37	41	44	47	48
Ratio 100:	104	100	91	85	79	77	74	74	74	76	77	80	81	85	86

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
July-Snowflake	24	20	21	24	26	30	35	41	46	51	56	61	65	66	68
Snowflake	26	22	21	22	22	23	25	28	31	34	37	41	44	47	48
Ratio 100:	103	110	100	92	85	77	71	68	67	67	66	67	68	71	71

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
July-Snowflake	24	20	21	24	26	30	35	41	46	51	56	61	65	66	68
Red Marrow-Snowflake	25	22	23	26	28	30	34	38	42	45	48	51	54	55	56
Ratio 100:	104	110	110	108	108	100	97	93	91	88	86	84	83	83	82

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
July-Snowflake	24	20	21	24	26	30	35	41	46	51	56	61	65	66	68
Triumph-Snowflake	21	18	19	20	21	23	25	28	31	33	35	37	38	39	39
Ratio 100:	88	90	90	83	81	77	71	68	67	65	63	61	58	59	57

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Red Marrow-Snowflake	25	22	23	26	28	30	34	38	42	45	48	51	54	55	56
Triumph-Snowflake	21	18	19	20	21	23	25	28	31	33	35	37	38	39	39
Ratio 100:	84	82	83	77	75	77	74	74	74	73	73	73	70	71	70

From these comparisons, it is seen that the differences in potential internode length between the bush beans, Triumph and Red Marrow, and the pole beans, July and Snowflake, as indicated by the previous comparisons of mean lengths of the first five internodes, are realized roughly in crosses between the bush and the pole beans. Thus the internode length of the Triumph-Snowflake cross is less than that of Snowflake, but the difference is not so great as that between Triumph and Snowflake. The mean-length ratio of Snowflake to Triumph, for the first five internodes, was 100:64 and that of Snowflake to the Triumph-Snowflake cross, for the first 15 internodes, was 100:81. The cross, therefore, occupied a position intermediate between its parents with respect to internode length, which was to have been expected.

Again, the direct comparisons indicated that the internode length of Red Marrow was potentially greater than that of Snowflake but less than that of July. The Red Marrow-Snowflake cross showed that this was true. The mean-length ratio of the Red Marrow-Snowflake cross to Snowflake, at the end of the fifteenth internode, was 100:86, while that of the July-Snowflake cross to Snowflake was 100:71 and that of July to Snowflake was, as shown earlier, 100:52. That is, the Red Marrow-Snowflake cross had an internode length greater than that of Snowflake, but the difference between Snowflake and the Red Marrow-Snowflake cross was not so great as the difference between Snowflake and the July-Snowflake cross, which in turn, of course, was not so great as the difference between July and Snowflake. That the potential internode length of Red Marrow is less than that of July is also shown by the comparison between the July-Snowflake and Red Marrow-Snowflake crosses, the length-ratio of which, for the first 15 internodes, was 100:82.

That the potential internode length of Triumph is considerably less than that of Red Marrow, as was earlier indicated by direct comparison of the first five internodes of these bush races by which a mean-length ratio of 100:58 was indicated, is shown by a comparison between the Red Marrow-Snowflake and Triumph-Snowflake crosses, between these crosses and Snowflake, and between them and the July-Snowflake cross. The internode length of the Triumph-Snowflake cross was 81 per cent of that of Snowflake which was only 86 per cent of that of the Red Marrow-Snowflake cross. Again the internode length of the Triumph-Snowflake cross was 57 per cent and that of the Red Marrow-Snowflake cross 82 per cent of the internode length of the July-Snowflake cross. From either of these comparisons, it follows that the internode length of the Triumph-Snowflake cross is 70 per cent of that of the Red Marrow-Snowflake cross, and this is also shown by the direct comparison of these crosses.

That this difference between the Red Marrow-Snowflake and Triumph-Snowflake crosses, as determined from the first 15 internodes, is much less than the difference between Red Marrow and Triumph, as determined from the first five internodes, is not to be taken as an indication that differences in potential internode length of bush beans are not suggested even roughly by direct comparison. That the difference between the crosses was less than the difference between the races themselves was to have been expected, since Snowflake was intermediate between the bush races in internode length and should, therefore, produce crosses with these races having internodes shorter than those of Red Marrow and longer than those of Triumph. If the Red Marrow-Snowflake cross were exactly intermediate between Red Marrow and Snowflake and the Triumph-Snowflake cross exactly intermediate between Triumph and Snowflake, the difference between the two crosses should be one-half the difference between Red Marrow and Triumph. The difference between the crosses was 30 per cent of the larger cross (100 − 70) and the difference between the bush races was 42 per cent of the larger race (100 − 58). The difference between 30 per cent and 21 per cent (one-half of 42 per cent) seems a fair measure of the accuracy with which differences in potential internode length of bush beans can be judged from a comparison of the actual internode lengths of the bush beans themselves.

The foregoing comparisons, as a whole, indicate that the potential internode lengths of bush beans can be determined roughly from measurements of the first five internodes. The length of the first 15 internodes is thought to give a fair approximation

to the mean internode length of pole beans. In general the period of growth-rate acceleration is finished by the time the fifteenth internode has developed. It is true that in some plants retardation in rate of growth begins somewhat earlier, but the retardation is so slow at first that the mean internode length is approximately the same whether it is calculated on the basis of 15 internodes or of a few more or a few less internodes. Since the growth-curve for the period of retardation in growth is roughly the reverse of the curve for the period of acceleration in growth, the mean length of the internodes developed during the acceleration period is not far from that of the entire plant. Thus the internode length of Snowflake, as grown in 1912, was 46 mm. for the first 15 internodes and 48 mm. for the entire length of the plants. Similarly the mean internode length of F_1 of a cross of Snowflake with a very tall bush bean was 86 mm. for the first 15 internodes and 82 mm. for the entire length of the plants. It is believed that the plant's inherent growth tendencies are better shown during the period of growth acceleration than at any later period. The period is short and during it, therefore, the plants are not subjected to so wide a range of weather conditions as during their whole period of growth. Moreover, the practical difficulties to be overcome in measuring all the internodes of pole beans are considerable. The upper part of such plants is usually badly tangled. The main axis is increasingly more liable to injury from the wind in its higher internodes. From all of these considerations it has been deemed best to include in the following presentation of results a consideration of on'y the first 15 internodes of pole beans and the first five internodes of bush beans.

INHERITANCE OF INTERNODE LENGTH.

The races of beans employed in this study were, in the main, the same races—in fact the identical cultures—employed in the study of the inheritance of number of internodes, namely, the pole beans July and Snowflake and the bush beans Red Marrow and Triumph. The peculiarities of growth of these races have been considered in some detail in the preceding discussion of methods of calculating internode length. A note regarding the previous breeding of the plants used in this study should be added. Except for a part of the plants of Red Marrow, the pedigree of all plants of any one race, the records of which are presented here, centers in a single self-pollinated plant three generations back, four plants in all, one for each race. All the crosses, likewise, trace back to the same four plants. These four plants were from

guarded pedigree cultures which had been under observation for two generations, except the July plant, in which case the pedigree ran back only one generation.

The records reported here were made in 1912 from plants grown in the garden. All the families containing pole beans were grown together in a small part of the garden. Owing to lack of room in this place, the bush-bean families were grown a few rods away on practically the same soil but where exposure to the wind was somewhat greater. Tho the differences were not great, the conditions as a whole were somewhat more favorable where the pole-bean families were grown. Even in this small part of the garden, the conditions with respect to soil moisture were not as uniform as desirable. Owing to the dry weather, all the plants were irrigated early in the season and again later. One end of the pole-bean garden was more difficult to irrigate thoroly than the rest and, in consequence, received somewhat less water. Fortunately the different races and crosses were arranged in planting so that all of them extended across both the drier and moister parts of the garden, except the F_1 families which, owing to the small number of plants, did not extend entirely across the garden. For this reason, as well as because of the small numbers grown, the records of F_1 plants are not entirely comparable with those of F_2 and of the parent races. The plants of each parent race and of each F_2 generation formed two rows across the garden. The records for these several lots are, therefore, it is believed, fairly comparable, tho the amount of variation within all the lots was increased to a certain extent by the somewhat unequal conditions at the two ends of the garden.

In Table 4, are presented the data obtained from the four races and their crosses with respect to mean lengths of the first five internodes. As thus determined, the mean internode length of the bush-bean races was 24.41 ± 0.31 mm. for Red Marrow and 14.28 ± 0.24 mm. for Triumph. The F_2 generation of the cross between these races had a mean internode length of 19.53 ± 0.39 mm., almost exactly half way between the means of the parents. The range of variation in F_2 extended from the lower extreme of Triumph to the upper extreme of Red Marrow. The standard deviation and coefficient of variation of the F_2 plants were somewhat greater than those of either parent and considerably greater than the parents' average. Evidently internode length in bush beans is inherited in much the same way as internode length in maize and as many quantitative characters in various plants are known to be (Emerson and East 1913).

The pole beans, July and Snowflake, and the cross between them present a different condition. True, the mean length of the

first five internodes of the F_2 plants, 26.36 ± 0.54 mm., is very nearly exactly intermediate between the means of the parents, 30.09 ± 0.77 and 22.65 ± 0.32 for July and Snowflake, respectively. But both the standard deviation and coefficient of variation for F_2 are less than these constants for one of the parent races, July, tho they are considerably greater than those for the other parent race, Snowflake. Of itself, the fact that the coefficient of variation for F_2 is slightly greater than the average of the coefficients for the parent races cannot be used to show a segregation in F_2 of genetic factors for internode length, unless, by the same reasoning, we are forced to admit also that there is segregation of an even greater number of genetic factors in case of the parent race July. While it is not unlikely that July is still heterozygous for factors concerned in internode length, it is highly improbable that it is heterozygous for more factors than F_1 plants of a cross between it and the very distinct race, Snowflake. If the high coefficient of variation for F_2, 25.61 ± 1.55 per cent, is due to segregation of size factors as seems probable from other considerations, the still higher coefficient for July, 32.67 ± 2.64 per cent, is yet to be explained.

It seems likely that the great variation exhibited by July, with respect to mean length of the first five internodes, is a chance relation of its peculiarities of growth in the early stages of its development to the somewhat uneven soil moisture conditions of the different parts of the garden as noted above. From the data presented in the discussion of methods of determining internode length, it will be recalled that, tho July is extremely vigorous in growth after once growth is well started, its first two or three internodes are unusually short—shorter even than those of the much less vigorously growing Snowflake. The mean lengths of each of the first seven internodes as determined from measurements of 83 plants of July and 78 plants of Snowflake are repeated here:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**	**7**
July	19	14	23	41	56	78	115
Snowflake	26	17	20	24	25	28	38

Since the first internodes of July are so very short and somewhat later ones so very long, the change in internode length is necessarily extremely rapid. If now this abrupt acceleration in growth-rate should begin in one plant with the fourth internode and in another with the sixth—as might easily happen if, owing to a slight difference in soil moisture, the one plant germinated a little later than the other, so that the one had developed only three internodes while the other had developed five at the time of a heavy rainfall—the mean length of the first five internodes

would be strikingly different in the two plants. And, if a number of such cases occurred, the coefficient of variation in mean length of the first five internodes might be very high, even tho the ultimate heights of the several plants were almost the same and the mean length of the first 15 internodes showed little variation. That just such differences in the initiation of growth-rate acceleration did occur in the July bean is shown by the measurements of the first six internodes of two plants of the same family (3,434) that ultimately reached approximately the same heights. The individual internode lengths in millimeters were:

Internode No	**1**	**2**	**3**	**4**	**5**	**6**
First plant	22	16	38	96	126	220
Second plant	20	17	39	54	85	176

The total lengths of the first five internodes were 298 mm. and 215 mm. and the mean lengths, therefore, 59.6 mm. and 43.0 mm., respectively. The total lengths of the first 15 internodes of these same two plants were 1,579 mm. and 1,619 mm. and the corresponding mean internode lengths, therefore, 105 mm. and 108 mm., respectively. In short, July bean plants may exhibit great differences in mean length of the first five internodes and almost no difference in mean length of the first 15 internodes.

In this connection the relative variation in length of particular internodes is worth noting. The coefficients of variation for each of the first five and for the tenth internodes of July (83 plants) and Snowflake (78 plants) are given below:

	July	Snowflake	Difference
First internode	17.08 ± 0.95	16.77 ± 0.90	0.31 ± 1.31
Second internode	24.36 ± 1.17	20.76 ± 1.35	3.60 ± 1.79
Third internode	35.40 ± 1.33	23.48 ± 2.07	11.92 ± 2.46
Fourth internode	47.16 ± 1.78	30.29 ± 2.97	16.87 ± 3.46
Fifth internode	45.25 ± 1.35	23.74 ± 2.81	21.51 ± 3.12
Tenth internode	28.29 ± 2.24	35.55 ± 1.61	-7.26 ± 2.76

July shows considerably more variation than Snowflake in the third, fourth, and fifth internodes, somewhat less in the tenth internode, only slightly more in the second internode, and no appreciable difference in the first internode. While the coefficient of variation for mean length of the first five internodes of July was 32.67 ± 2.64 per cent and that of Snowflake 15.81 ± 1.01 per cent (Table 4), or a difference of 16.86 ± 2.83, these constants for the first 15 internodes (Table 5) were for July 26.11 ± 1.52 per cent and for Snowflake 27.68 ± 1.86 per cent, an insignificant difference of 1.57 ± 2.40. As will be shown later, when the first 15 internodes instead of only the first five are considered, segregation of internode length factors in F_2 is more plainly indicated.

Since the behavior of July with respect to mean lengths of the first five internodes has been shown to be so irregular, it could hardly be expected that the crosses between July and the bush beans, Triumph and Red Marrow, would give reliable evidence of segregation of internode length factors from measurements of the first five internodes. But there is no other comparison available for the F_2 bush segregates of these crosses. The coefficient of variation of the F_2 bush segregates of the July-Triumph cross (Table 4) was less than that of July by 10.80 ± 3.74 and practically the same as that of Triumph, the difference being only 0.19 ± 2.93. The coefficient of variation of the F_2 pole segregates of this cross was slightly greater than that of the bush segregates but not equal to that of July, the difference being 5.40 ± 3.29 and 5.40 ± 3.28, respectively. In F_2 of the July-Red Marrow cross, the coefficient of variation for mean length of the first five internodes was much greater than that of Red Marrow and somewhat greater even than that of July. In the statement below, the pole-bean segregates of F_2 of the July-Red Marrow cross are compared with July and the bush-bean segregates with Red Marrow. The calculations were made from measurements of 74 plants of July, 71 of Red Marrow, 57 of the F_2 pole-bean segregates, and only 12 of the F_2 bush-bean segregates. The coefficients of variation of these four lots of plants for each of the first five internodes are:

Internode No	**1**	**2**	**3**	**4**	**5**
July-Red Marrow, F_2 pole	19.65	27.52	48.62	66.06	49.06
July	17.08	24.36	35.40	47.16	45.25
Difference	2.57	3.16	13.22	18.90	3.81
Internode No	**1**	**2**	**3**	**4**	**5**
July-Red Marrow, F_2 bush	19.46	15.74	46.27	52.54	64.27
Red Marrow	15.20	22.15	20.51	23.18	28.28
Difference	4.26	−6.41	25.76	29.36	35.99

That such differences in the coefficients of variation as those between July and the F_2 pole-bean segregates, as given above, are indications of segregation in F_2 of internode-length factors which differentiate the parent races seems unlikely.

The F_2 segregates of the July-Triumph cross showed consistently smaller coefficients for the first five internodes considered individually than did July, notwithstanding the fact that July and Triumph differ more in mean internode length than July and Red Marrow and probably also, therefore, in more internode-length factors. The whole question with respect to these crosses can be decided only by further investigation if indeed any decision can be reached from measurements of only the first five internodes. It may be noted here, tho this will be presented in detail later,

that the F_2 pole-bean segregates of the July-Triumph cross, as well as of the July-Red Marrow cross, showed greater variation than did July with respect to mean lengths of the first 15 internodes.

From Table 4 it is seen that the variation in mean lengths of the first five internodes of the F_2 pole-bean segregates of the Snowflake-Triumph cross is less than that of either parent race. The F_2 bush-bean segregates of this cross, on the other hand, had a greater variation than either parent race. When the individual internodes are considered separately, it is found that the standard deviations are, as a rule, greater for F_2 than for the parent races. The very small mean internode lengths of Triumph, however, make the coefficients of variation for that race larger in many cases than those for the F_2 plants. It is possible that the mean internode lengths of Triumph are relatively smaller than they should have been owing to the fact that the conditions under which the bush-bean families were grown were somewhat less favorable than those surrounding the pole-bean families. That this may be true is suggested by the fact that the mean internode length of the F_2 pole-bean segregates is considerably nearer that of Snowflake than that of Triumph—but this difference may in part be due to a somewhat increased vigor arising from partial heterozygosis in F_2. If normal internode lengths in Triumph and Snowflake are more nearly alike than indicated by the values found here from the first five internodes, less variation would be expected in F_2 than if the difference between internode lengths of the parents were greater, but this variation should certainly not, even then, be less than that of the parents. From the data at hand, it cannot be said that any segregation occurs in factors for mean length of the first five internodes.

The only cross between pole and bush beans yet to be considered with respect to mean lengths of the first five internodes (Table 4) is that between Red Marrow and Snowflake. The mean lengths of the first five internodes are nearly the same for both parent races, but the mean lengths for both generations of the crosses are greater than for either parent. This, like the results of the Triumph-Snowflake cross, may be due in part to the somewhat unfavorable conditions under which the bush-bean families were grown, whereby the internode length of Red Marrow was less than it would otherwise have been. If this is true, the same condition, which may have made the internode lengths of Snowflake and Triumph differ more than they should, would tend to make the internode lengths of Snowflake and Red Marrow more nearly alike than they otherwise would have been. If, on further investigation, these conjectures are substantiated, that is, if

Triumph and Snowflake are found to have nearly equal internode lengths while Red Marrow and Snowflake are found to have quite unlike internode lengths, the fact that the variation in F_2 of the Triumph-Snowflake cross was no greater than the variation in the parent races would be readily understood, as already pointed out, but greater variation would then be expected in F_2 of the Red Marrow-Snowflake cross than in the parent races. That this was just what occurred is seen from the data given in Table 4. For mean lengths of the first five internodes, the coefficients of variation are for Snowflake 15.81 ± 1.01 per cent, for Red Marrow 15.81 ± 0.91 per cent, for the F_2 pole-bean segregates 33.33 ± 2.16 per cent, and for the F_2 bush-bean segregates 22.86 ± 2.86 per cent. The range of variation in F_2 was 40 mm. for the pole-bean segregates and 25 mm. for the bush-bean segregates, as against 20 mm. for F_1, 20 mm. for Snowflake, and 15 mm. for Red Marrow. Increased variation of F_2 over the parent races was also shown for each individual internode of the first five.

By way of summary it can be said that there is distinct evidence of segregation in F_2 of factors for length of the first five internodes of two crosses between pole and bush beans. No evidence of such segregation has been found in case of two other such crosses. Where there is distinct segregation in F_2 it should be possible to isolate types of both bush and pole beans of different internode lengths from a single cross of pole and bush races. No F_3 progenies of the crosses here under consideration have been grown, but very distinct types of bush beans with respect to internode length have been isolated from a cross of other varieties. The evidence of this will be given later.

Table 5 exhibits the variations in length of the first 15 internodes of some of the races and crosses discussed above. It is obvious that only plants of indeterminate growth habit can be included in the table. This eliminates from the comparison not only the bush races and crosses between bush races but also the F_2 bush segregates of pole-bush crosses. For the races and crosses that can be included here, the data are more reliable than those for the first five internodes. The reasons for this were discussed in the consideration of methods of calculating internode lengths. The mean length of 15 internodes is a better measure of internode length than the mean length of only five internodes.

The mean length of the first 15 internodes in F_2 of the July-Snowflake cross, 69.29 ± 1.99, is almost exactly intermediate between the means of the parent races, 89.69 ± 1.84 for July and 46.28 ± 1.13 for Snowflake. In range of variation, the F_2 plants extend to the outer extremes of the two parents. The coefficients of variation are 27.68 ± 1.86 for Snowflake, 26.11 ± 1.52 for July,

21.20 ± 1.90 for F_1 of the cross between them, and 36.90 ± 2.37 for F_2 of the same cross. The indication here of an F_2 segregation of internode-length factors in a cross between two pole beans of very unequal internode length is fairly definite.

In every one of the four crosses between pole and bush beans, the F_2 pole-bean segregates exhibit somewhat greater variation than the pole-bean parent, as measured by the coefficient of variation, but not always as measured by the standard deviation. The coefficients of variation for July and Snowflake and for the F_2 families of their crosses with bush beans are:

July	26.11 ± 1.52 per cent
July-Triumph F_2	32.97 ± 2.43 per cent
July-Red Marrow F_2	29.62 ± 2.03 per cent
Snowflake	27.68 ± 1.86 per cent
Snowflake-Triumph F_2	28.20 ± 2.02 per cent
Snowflake-Red Marrow F_2	31.74 ± 2.02 per cent

While the indications are not so clear in some of these crosses as in others, the evidence as a whole favors the conclusion that there is segregation of internode-length factors in crosses between bush and pole beans, just as in crosses between two bush or two pole races that differ in internode length.

Whether there has been segregation of genetic factors for internode length in F_2 can be determined much more positively by the constant types that are isolated in F_3 or later generations than by statistical constants calculated from the F_2 generation and from the parent races.[1] No F_3 generation of any of the crosses considered here has been grown, but partial records of another cross give positive evidence of the production of bush beans of diverse types with respect to internode length. The cross in question is that between Longfellow, a bush bean with rather short internodes, and Fillbasket, a pole bean with fairly long internodes. The data for internode length were obtained from the same cultures as the data for number of internodes, which were presented earlier in this paper.

From a small F_2 family of the Longfellow-Fillbasket cross, grown in the greenhouse in 1909, a very tall bush segregate was chosen and a few F_3 plants were grown from it in the garden in 1910. One of the tallest plants of this F_3 family was the parent of

[1] Shull (1914) has pointed out the fact that increased variability of quantitative characters in F_2 might be due to the unequal stimulation of various degrees of heterozygosis (unequal heterosis) of factors other than those directly concerned in the development of the quantitative characters in question and that somewhat diverse F_3 types might also be due to different average degrees of heterozygosis. No constant difference between extracted types could, however, be accounted for in this way.

an F_4 family (3,251) grown near Boston, Massachusetts, in 1911. A medium small bush plant was also chosen from the same F_2 family, a small F_3 family grown from it, and a medium small F_3 plant chosen as the parent of an F_4 family (3,254), also grown near Boston. In the same garden with these F_4 families, were several lots of the parent race, Longfellow, all descended directly from the individual plant used in making the Longfellow-Fillbasket cross. All these lots of the bush parent were much alike in height. The plants of one of them (3,247) were measured for comparison with the two very unlike F_4 families. In making these records the total length of the main axis and the total number of internodes were determined instead of measuring each internode separately, as has been done in most of the more recent work. The internode lengths reported here were calculated from the data recorded. As has been pointed out before, this does not give as accurate a measure of mean internode length as is obtained from a definite number of internodes, but it does nevertheless give some notion of differences in internode lengths between the three lots. Statistical constants for the three lots of plants are:

	Number of individuals	Mean	Standard deviation	Coefficient of variation
Longfellow (3,247)	18	27.7 ± 0.7	4.6 ± 0.5	16.5 ± 1.9
Longfellow-Fillbasket F_4 (3,254)	36	22.3 ± 0.6	5.3 ± 0.4	23.7 ± 2.0
Longfellow-Fillbasket F_4 (3,251)	41	54.2 ± 1.5	14.7 ± 1.1	27.1 ± 2.2

One of the F_4 families had, it is seen, somewhat shorter internodes than the family chosen to represent the bush parent of the cross, while the other F_4 family had internodes almost twice as long as the parent race. It is probable that the several families of the bush-bean parent would have been found to differ somewhat in internode length, had they been measured, but certainly no such difference existed between them as between the two F_4 families.

Since these F_4 families not only differed much in internode length but also showed some difference in number of internodes (Table 3), it follows that they differed also in height of plants. In fact the difference in this respect was remarkable. F_4 family No. 3,251 was one of the tallest lots of bush beans that I have ever seen. The mean length of the main axis in Longfellow (3,247) was about 137 mm., in the short F_4 family (3,254) about 121 mm., and in the tall F_4 family (3,251) about 349 mm. The extreme difference in height of plants of these families is shown in Figure 15. It is plain, then, that, while the segregation into pole and bush beans in F_2 of a pole-bush cross is as definite as segregation in any simple Mendelian character, some of the bush segregates at least are very unlike the bush parent in height of plant.

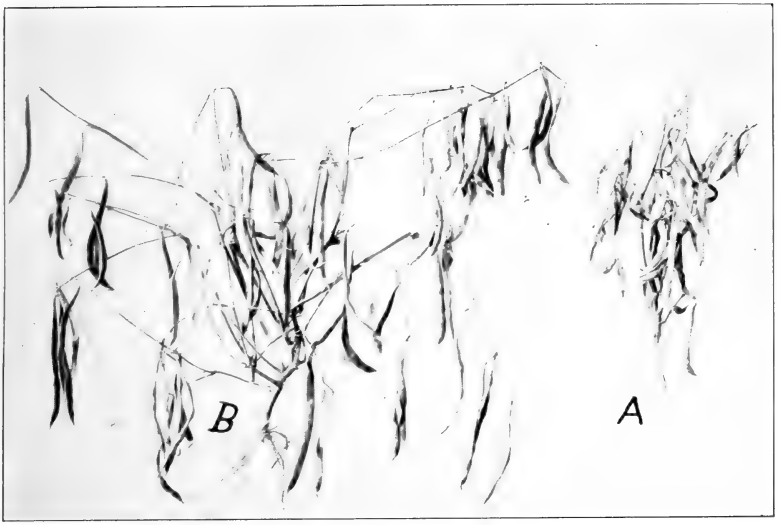

Fig. 15.—Representative plants of (A) a race of short bush beans, Longfellow, and (B) a race of tall bush beans, Tallbush, established from a cross between Longfellow and a tall pole bean.

The very tall bush-bean type, isolated as noted above (Family 3,251) from a cross between a rather short bush bean and a fairly tall pole bean, has been grown for some generations and found to be fairly constant. The race will be known here as Tallbush. Since Tallbush inherited its tallness from a tall pole bean (the other parent race being a short bush bean), it is of interest to note that it transmits tallness to a part of its pole-bean progeny when crossed with a very short pole bean.

The short pole bean chosen for one parent of this cross was Snowflake and the plants used were directly descended from those employed in the crosses with Red Marrow, Triumph, and July, discussed earlier in this paper. The Tallbush plant used in this cross was a direct descendant one generation removed from the F_4 family 3,251 of the Longfellow-Fillbasket cross noted above.

In 1912 the parents and F_1 of the Snowflake-Tallbush cross were grown in the garden along with the plants recorded in Tables 4 and 5. The following winter a few plants of both parent races, a single plant of F_1 and a considerable number of plants of F_2 of the cross, were grown in the greenhouse in 6-inch pots of rich soil under conditions of temperature and moisture favorable to rather excessive length growth.

The mean internode lengths, as calculated from the first five internodes, of the garden-grown parent races and F_1 are given in Table 6. Snowflake and Tallbush had mean internode lengths of 22.65 ± 0.32 and 44.76 ± 0.93, respectively. The mean of F_1 was 29.62 ± 0.59, which is considerably below the average of the means of the parents. While the coefficient of variation of F_1, 17.23 ± 1.45, is somewhat greater than that of the parents, 15.81 ± 1.01 and 12.76 ± 1.50, it is not sufficiently so to demonstrate a significant difference in variability.

Data for F_2 of the Snowflake-Tallbush cross are given in Table 7. As noted above, these plants were grown in the greenhouse during winter. Only a few plants of the parent races and only one plant of F_1 were grown for comparison. Tallbush responded to the relatively high temperature and humidity and weak light of the greenhouse much more pronouncedly than did Snowflake, the internode length of the few plants grown being more than twice that of the same race as grown in the garden the summer before. It seems quite possible that a similar difference in response to the greenhouse conditions on the part of the several plants of F_2 may account in part for the rather remarkable range of variation in internode length exhibited by that lot of plants. The average length of the first five internodes of the F_2 plants included in its range the extremes of the parent plants. It is noteworthy that this variation was quite as marked in the pole beans of F_2 as in the bush plants. The tendency to produce long internodes, characteristic of the bush parent, was transmitted to a part of the pole-bean as well as to a part of the bush-bean offspring. Quite as noticeable is the fact that the tendency to form short internodes, a characteristic of the pole-bean parent, was transmitted to a part of the bush plants as well as to a part of the pole plants of F_2. Here, just as in crosses between tall pole beans and short bush beans, habit of growth segregated in a 3-1 way—88:31 to be exact—but both determinate and indeterminate types of plant were in fact very different from the respective determinate and indeterminate parent stocks.

While the internode length of F_1 was distinctly intermediate between the internode lengths of the parent races (Table 6) and while the internode lengths in F_2 ranged from one parent type to that of the other (Table 7), the height of the F_1 plants was by no means intermediate between the parents, nor was the F_2 range in height confined to the parental extremes. The heights of the F_2 plants are shown in Table 8. The few very long internodes of the determinate parent, Tallbush, as grown in the greenhouse, made it practically equal the height of the indeterminate parent, Snowflake, with its more numerous but much shorter internodes.

Fig. 16.—Representative plants (A) of the short pole bean Snowflake, 3,958, (B) of the tall bush bean Tallbush, 3,957, (C) of the F_1 of the cross between Snowflake and Tallbush, 3,959, (D) of the pole segregates and (E) of the bush segregates of F_2 of the same cross, 3,961.

The F_2 bush plants were on the whole considerably shorter than the bush parent, none being so tall as the taller plants of Tall-bush. It was among the F_2 pole-bean plants, however, that the most remarkable variation was exhibited. The smallest of these plants were only about 35 centimeters high—shorter than any of the few plants of Snowflake grown with them but not much shorter than are sometimes found among weak plants of that race. At the other extreme were plants nearly 200 centimeters tall—a height not materially less than that attained by the taller races of pole beans when grown in as small pots as were these F_2 plants.

The great variation in height of the F_2 plants of this cross is perhaps made even more obvious by the photographs reproduced in Figure 16. It seems a clear inference from the data here presented that a tall race of bush beans, which inherited its relatively great height from a tall pole-bean parent of an earlier cross, has transmitted tallness to its pole-bean progeny when crossed with a very short pole bean. Other factors for height of plant are, then, inherited independently of habit of growth.

FACTORS FOR PLANT HEIGHT—THEIR SEGREGATION AND POSSIBLE MODIFICATION IN CROSSES.

It was noted in the introduction to this paper that quantitative characters, including height of plants in maize at least, are usually intermediate between the parents in F_1 and show a wide range of variation in F_2, thus furnishing a basis for the isolation of numerous quantitatively distinct types in F_3. It was also noted that some quantitative characters, particularly height of plants of several very diverse groups including beans, exhibit perfect dominance in F_1, followed by simple 3:1 segregation in F_2 and typical Mendelian behavior in later generations. That height of plants should in some cases fall into the one and in other cases into the other of these two classes of behavior presents an important problem. If the inheritance of quantitative characters in general is to be interpreted on the basis of the multiple-factor hypothesis, it is to be expected that some quantitative characters will be found to differ by only a single genetic factor just as other quantitative differences may be due to three or four or ten factors. It seems probable, then, that, within any one species, and with respect to the same plant part, great quantitative differences are in general due to many factors and small quantitative differences to one or to a few factors, tho of course it is not maintained that all size factors, even in this restricted case, necessarily have equal value. (In this connection see Shull 1914.) But the 3-1 segregation, denoting a single-factor difference, is

seen in crosses between tall and dwarf (pole and bush) beans whether the difference in height of the parents is very great or only medium.

Evidence has been presented in this paper to show that very tall and very dwarf beans (pole and bush beans) differ by a single fully dominant genetic factor for habit of growth. Pole beans are indeterminate in habit, growth continuing apparently as long as conditions are favorable. Bush beans are determinate in growth, the main axis being terminated by the inflorescence. One genetic factor for growth habit differentiates a very tall pole bean from a very dwarf bush bean just as sharply as it does a medium short pole bean from a medium tall bush bean.

Evidence has also been presented to show that height of plant in beans is influenced by other genetic factors independent of habit of growth. These factors have to do with number of internodes and with internode length. It has been shown that pole-bean races, equally indeterminate in habit of growth, may differ considerably in the number of internodes ultimately produced and also in the length of particular internodes and the mean length of all internodes. Bush beans also differ much in internode length and somewhat in number of internodes. Tho the evidence presented here is not all that might be desired, it is believed to be sufficient to show that both internode length and number of internodes in beans are inherited in the same way that most quantitative characters in plants are. An intermediate development in F_1 (often masked by the increased vigor of heterozygosis), increased variation in F_2, and the isolation of distinct types in later generations have been shown. The fact that the F_2 generation of some crosses was not more variable than one or other of the parent races—whether or not this be due to irregularities discoverable in the parent races—cannot displace the positive evidence of increased variation in other crosses.

It seems clear that, if the production of types unlike either parent in number of internodes or in internode length is due to a segregation of independent, nondominant factors for number of internodes or internode length in crosses between two unlike bush beans or in crosses between two unlike pole beans, then, a similar result must be interpreted in the same way in case of crosses between a pole bean and a bush bean.

From a cross between a tall pole bean and a short bush bean, there resulted in F_2 a distinct segregation into approximately three pole beans to one bush bean. Evidently there existed between the parents a single-factor difference for habit of growth. But while these pole-bean segregates were all indeterminate in habit of growth some of them were much shorter than the pole-

bean parent race, and, likewise while the bush segregates were all determinate in habit of growth, some of them were much taller than the bush-bean parent race. We need not conclude from this, however, that the single factor for habit of growth by which the parent races differed was modified in some way by the cross, so that, while only determinate and indeterminate habits were to be seen in F_2, they were in part of the individuals modified determinate and modified indeterminate habits. It seems more likely that there existed other factors for the difference in height of the parent plants besides the factor for habit of growth and that segregation of these other factors was responsible for the different heights of bush beans and the different heights of pole beans noted in the F_2 generation.

From one of the very tall F_2 bush plants of this cross there has been established a race of very tall bush beans, known here as Tallbush, (Figs. 9 and 15) and this has been crossed with a race of very short pole beans, Snowflake (Fig. 9). Tall pole beans resulted in F_1 and there was a wide range of variation in height of both the pole and bush segregates in F_2. Apparently the factors for number of internodes and for internode length, which this very tall race of bush beans received from the tall pole-bean parent of the original cross, are able to reproduce the tallness of that parent when associated with the factor for indeterminate growth secured from a very short pole bean. And, moreover, these factors have apparently segregated to produce diverse heights in both the pole and bush plants of this later F_2 generation from the cross between the tall bush bean and the short pole bean just as they did to produce the diverse types of the earlier F_2 generation from the cross between the tall pole bean and the short bush bean.

If we were to account for these results by assuming a modification of the factor for determinate growth thru the influence of the tall pole bean employed as one parent of the original cross, we should have also to make the following additional assumptions: (1) That the modification affected the bush habit in different degrees in the case of the several F_2 bush plants, (2) that the modification is constant in the new tall bush race, (3) that the modified determinate habit was remodified in the cross between the tall bush race and the very short pole race, the modification again affecting only a part of the F_2 bush plants, (4) that this remodified determinate habit was able to modify the indeterminate habit in a very definite way in the cross with the short pole bean, so that the F_1 plants were all very tall pole beans, and finally (5) that this new modification of the indeterminate habit was able to appear in only a part of the pole-bean segregates of F_2.

The modification would then also have to be used in interpreting the results secured from crosses between two bush races or two pole races of different heights, for there seems to be no fundamental difference between such crosses and crosses between a pole bean and a bush bean. But, for the results from crosses of unlike bush or pole beans, the multiple-factor hypothesis affords a much more simple and direct explanation. It accounts for the intermediate development in F_1, for the wide range of variation in F_2, and for the constancy of some and inconstancy of other F_2 types.

In many respects the results secured from crosses between pole and bush beans resemble the results obtained from crosses between hooded and Irish rats (MacCurdy and Castle 1907), and hooded and wild rats (Castle 1912). When hooded rats—characterized by pigmented head, shoulders, and forelegs and median dorsal stripe and white over the rest of the body—were crossed with Irish rats—characterized by pigmented sides and dorsal surface and a variable white area on the ventral surface—the Irish pattern was dominant in F_1 and segregation into Irish and hooded patterns with a 3-1 ratio occurred in F_2, but the pigmented area in the hooded segregates was increased as was also the range of variation in amount of pigmentation. From this MacCurdy and Castle conclude:

> "Again, though the inheritance is clearly Mendelian, when hooded and Irish rats are crossed, the gametes formed by cross-breds are not pure, but modified, each pattern being changed somewhat in the direction of that pattern with which it was associated in the cross-bred parent."

A strain of hooded rats with extensive pigmentation and a strain with restricted pigmentation were established by selection. When crossed with wild rats—totally pigmented—each hooded strain behaved as a simple Mendelian recessive, but the hooded segregates from the cross of wild rats with the extensively pigmented hooded pattern were more extensively pigmented than the hooded segregates from the other cross. Crosses between hooded rats with restricted pigmentation and hooded rats with extensive pigmentation gave results similar to most crosses where the parents differ quantitatively. (Castle and Phillips 1914.)

The fact of simple Mendelian segregation in such crosses has led Castle to maintain that only a single unit-character is involved in the experiment (Castle 1912, 1914), tho he admits the possibility that additional factors may be concerned (Castle and Phillips 1914) as first suggested by East (1912) and later discussed by the Hagedoorns (1914) and Muller (1914). That the hooded pattern differs from the Irish pattern in a single genetic factor will be readily admitted. That there are no additional factors

influencing the extent of pigmentation in the hooded pattern but unable to influence the Irish pattern is not so clear. The behavior of crosses between a hooded strain with extended pigmentation and one with restricted pigmentation affords support to the idea of such additional factors as do also the results of crosses between Irish rats and rats with extended hoods whereby the hoods of F_2 segregates are restricted rather than further extended. In short, it seems possible that restricted hood may differ from extended hood by one to several genetic factors, just as tall bush beans seem to differ from short bush beans, and that Irish pattern may sometimes possess and sometimes lack factors for extension of the hooded pattern, just as tall pole beans seem to possess and short pole beans to lack some factor or factors for internode length or internode number—factors which, it appears, can be inherited independently of habit of growth and thereby be transferred from pole to bush or from bush to pole beans.

I will admit that at first it seems unlikely that a genetic factor could be present in the Irish pattern of rats together with the factor that differentiates the Irish from the hooded pattern, without interfering with the simple 3-1 segregation resulting from a cross between Irish and hooded rats. The existence of factors for internode length independent of factors for habit of growth in beans presents no such difficulty. Apparently the only relation that habit of growth bears to internode length exists merely by virtue of the circumstance that determinate habit arrests growth when the period of acceleration in growth-rate has barely begun, so that internode length of bush beans is ordinarily much less than that of pole beans. But to conceive the possible nature of factors for number of internodes independent of a factor for habit of growth in beans presents as great a difficulty as to conceive the possible nature of pigment-extension factors independent of pattern factors in rats.

The principal effect upon plant height of indeterminate growth is to extend the number of internodes almost indefinitely while that of determinate growth is to limit the development of internodes to a small and rather definite number. If there are, in addition to a single factor for habit of growth, other special factors for internode number, how can there result a simple segregation giving three plants with many internodes (indeterminate) to one plant with few internodes (determinate)?

Let us see whether the multiple-factor hypothesis—assumed thruout this paper to interpret the results as regards number of internodes in crosses between distinct bush beans and also in crosses between distinct pole beans—can be combined with the single-factor hypothesis—also used consistently to interpret the

facts with reference to the inheritance of habit of growth—so that the combination shall afford a true picture of the results secured from a cross between a tall pole bean and a short bush bean, or a short pole bean and tall bush bean. Let us assume that difference in habit of growth between pole and bush beans is due to the single factor A and that the difference between a tall bush bean and a short one or between a tall pole bean and a short one is due to the two factors B and C. Let us also assume that A is a dominant factor and that B and C are nondominant factors. Finally, the following values, which are to be added to an initial value of three internodes, will be assumed for the three factors:

$A = 10$ internodes
$B = 1$ internode
$C = 1$ internode

Because A is dominant and B and C are nondominant, these factors, when in the duplex condition, will have the following values:

$AA = 10$ internodes
$BB = 2$ internodes
$CC = 2$ internodes

A plant with the formula $AABBCC$ is then—environmental influence aside—a pole bean with 17 internodes, a plant $AAbbcc$ is a pole bean with 13 internodes, a plant $aaBBCC$ is a bush bean with 7 internodes and a plant $aabbcc$ is a bush bean with three internodes. A cross between $AABBCC$ and $AAbbcc$ would give an F_2 of all pole beans but with a somewhat greater range of variation than that of either parent. Likewise a cross between $aaBBCC$ and $aabbcc$ would produce nothing but bush beans, but the variation in F_2 would be greater than in either parent. Crosses between $AABBCC$ and $aaBBCC$, between $AAbbcc$ and $aabbcc$, between $AABBcc$ and $aaBBcc$, etc., would give, in F_2, three pole beans to one bush bean without an increased range of variation in either class over that of the parent races. Finally a cross between $AABBCC$ and $aabbcc$ or between $AAbbcc$ and $aaBBCC$ would result in F_2 in three pole beans to one bush bean and both of the F_2 classes would show greater variation than the parent races. The latter possibilities alone need be illustrated further. The formulae and numbers of internodes of the parents and F_1 would be:

Parent	$AABBCC$	= 17 internodes.
Parent	$aabbcc$	= 3 internodes.
F_1	$AaBbCc$	= 15 internodes.

Or:

Parent	$AAbbcc$	= 13 internodes.
Parent	$aaBBCC$	= 7 internodes.
F_1	$AaBbCc$	= 15 internodes.

The formulae, number of internodes and frequencies of the several F_2 types would be:

Frequencies	Formulae	Internodes	Frequencies	Formulae	Internodes
1	*AABBCC*	17	2	*AabbCC*	15
2	*AABBCc*	16	4	*AabbCc*	14
2	*AABbCC*	16	1	*AAbbcc*	13
2	*AaBBCC*	17	2	*Aabbcc*	13
4	*AABbCc*	15	1	*aaBBCC*	7
4	*AaBBCc*	16	2	*aaBBCc*	6
4	*AaBbCC*	16	2	*aaBbCC*	6
8	*AaBbCc*	15	4	*aaBbCc*	5
1	*AABBcc*	15	1	*aabbCC*	5
2	*AABbcc*	14	2	*aabbCc*	4
2	*AaBBcc*	15	1	*aaBBcc*	5
4	*AaBbcc*	14	2	*aaBbcc*	4
1	*AAbbCC*	15	1	*aabbcc*	3
2	*AAbbCc*	14	.	....	..

The frequency distribution for number of internodes found by assembling the above data is:

Internodes	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Frequencies	1	4	6	4	1						3	12	18	12	3
Bush beans	16							Pole beans	48						
Ratio	1								3						

From the illustration given above, it is seen that a combination of the multiple-factor and the single-factor hypotheses, previously employed separately, can be used to interpret the facts with regard to the inheritance of habit of growth and number of internodes in crosses between pole and bush beans. A 3-1 distribution of pole and bush types, together with wide variation in internode numbers in both classes, is realized as a result of the assumptions made. The range of variation observed in F_2 of the crosses of pole and bush beans reported in this paper is much greater for the pole-bean than for the bush-bean segregates. This difference is not expressed in the hypothetical frequency distribution given above. But no account is here taken of the influence of environmental conditions upon the number of internodes. In the discussions of habit of growth and of growth curves early in this paper, it was shown that environmental conditions exert a marked influence upon the number of internodes of pole beans while having little or no effect upon bush beans. Pole beans, in short, owing to their indeterminate habit, are capable of prolonged growth under favorable conditions but may have their growth arrested early by unfavorable conditions, while bush beans under very favorable conditions merely produce more branches, all of which are as determinate in growth as in the main

axis. The difference in variation between the pole and bush segregates in F_2 is no greater than that between pole and bush races.

In the hypothetical formulae employed here, the factor *A* for habit of growth is assumed to differ in no way from the factors *B* and *C*, except in regard to dominance and to the magnitude of its effect upon number of internodes. As a matter of fact, the factor *A* must differ in another respect from *B* and *C*, for the axis of a pole bean with relatively few internodes is not terminated by an inflorescence and can be forced to elongate almost indefinitely, while the axis of the tallest bush bean is terminated just as abruptly as that of the shortest bush bean. If *A* were a factor for habit of growth alone without other relation to internode numbers and *B* and *C* and their like mere modifying factors, some of them, perhaps, concerned in general vigor of growth, time of flowering and of seed production, etc., the results would be the same. It is probable that size factors in general interact one upon another during development, a single factor sometimes being concerned in the development of several characters commonly regarded as quite distinct and several factors at times being concerned in the development of a single character. Several indications of this sort have been observed in maize (Emerson and East 1913). In the present paper numerous illustrations of the interrelations of growth habit, internode number, internode length, time of flowering and seed production, and the like have been pointed out.

By way of conclusion, it may be said that the known facts in regard to the inheritance of the quantitative character height of plant in beans yield readily to an analysis based upon a modified multiple-factor hypothesis. The proposed modification consists merely of the assumption of inequality in dominance and inequality in potency of some of the factors concerned. It is probable that no geneticist would maintain that all the genetic factors concerned in the development of any quantitative character are necessarily equal in dominance or potency[1], but, since the actual potency of distinct quantitative factors has as yet been determined in no case and since the assumption of equal potency of two or more factors affords a simple and sufficiently accurate interpretation of quantitative inheritance, no other assumption seems necessary except in cases like the one now under consideration. Whether this modified multiple-factor hypothesis will account for the facts of inheritance of plant height in case of such types as tomatoes, peas, dwarf maize, etc., is a question for future determination.

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[1] For a discussion of this matter, see Shull 1914, and Muller 1914.

In presenting this factorial interpretation of inheritance of height of plant in beans, the writer disavows any intention of maintaining that this is the only possible interpretation of the facts presented. Castle's hypothesis of the modification of genetic factors is another such interpretation (Castle 1914a). Perhaps neither is correct. Both serve the purpose of working hypotheses, in so far as they suggest the direction of further researches. Since one hypothesis may suggest certain lines of further investigation and another hypothesis may suggest other lines, it is fortunate that we are not limited to a single hypothesis. The multiple-factor hypothesis has been adopted here because it seems to the writer to afford the more simple and direct interpretation of the known facts concerning the inheritance of quantitative characters. This statement is made with a full realization that, whatever hypothesis is adopted, it must interpret the facts of inheritance derived from selection experiments as well as those obtained from cross-breeding.

LITERATURE CITED.

BAILEY, L. H.

The dwarf Lima beans. Bul. Cornell, N. Y. Agr. Exp. Sta. 87:83-101. 1895.

BATESON, W., AND PUNNETT, R. C.

Sweet peas. Rpts. Evol. Com. Roy. Soc. 4:6-18. 1908.

CASTLE, W. E.

The inconstancy of unit-characters. Amer. Nat. 46:352-362. 1912.

Pure lines and selection. Jour. Heredity 5:93-97. 1914.

Size inheritance and the pure line theory. Zeit. induk. Abast. Vererb. 12:225-237. 1914a.

CASTLE, W. E., AND PHILLIPS, J. C.

Piebald rats and selection. Pub. Carnegie Inst. 195:1-56. 1914.

EAST, E. M.

The Mendelian notation as a description of phys'ological facts. Amer. Nat. 46:633-655. 1912.

EAST, E. M., AND HAYES, H. K.

Inheritance in maize. Bul. Conn. Agr. Exp. Sta. 167:1-142. 1911.

EMERSON, R. A.

Heredity in bean hybrids. Ann. Rpt. Nebr. Agr. Exp. Sta. 17:33-68. 1904.

The inheritance of sizes and shapes in plants. Amer. Nat. 44:743-744. 1910.

Genetic correlation and spurious allelomorphism in maize. Ann. Rpt. Nebr. Agr. Exp. Sta. 24:59-90. 1911.

Emerson, R. A., and East, E. M.
The inheritance of quantitative characters in maize. Research Bul. Nebr. Agr. Exp. Sta. 2:1-120. 1913.

Gilbert, A. W.
A Mendelian study of tomatoes. Ann. Rpt. Amer. Breeders' Assoc. 7:169-188. 1912.

Hagedoorn, A. L., and A. C.
Studies on variation and selection. Zeit. induk. Abst. Vererb. 11:145-183. 1914.

Hedrick, U. P., and Booth, N. O.
Mendelian characters in tomatoes. Proc. Soc. Hort. Sci. 5:19-24. 1907.

Keeble, F., and Pellew, C.
The mode of inheritance of stature and time of flowering in peas (*Pisum sativum*). Jour. Genetics 1:47-56. 1910.

Lock, R. H.
Experiments with peas. Annals Roy. Bot. Gard. Peradeniya. 2:357-414. 1905.

MacCurdy, H., and Castle, W. E.
Selection and cross-breeding in relation to the inheritance of coat-pigments and coat-patterns in rats and guinea pigs. Pub. Carnegie Inst. 70:1-50. 1907.

Mendel, G.
Versuche über Pflanzenhybriden. Verh. naturf. Ver. Brünn, Abhandlungen IV, 1865. Translation published in Jour. Roy. Hort. Soc. 26:3-32 (1901) and in Mendel's Prin. Heredity—A Defense, Bateson, pp. 40-95. 1902.

Muller, H. J.
The bearing of the selection experiments of Castle and Phillips on the variability of genes. Amer. Nat. 48:567-576. 1914.

Price, H. L., and Drinkard, A. W.
Inheritance in tomato hybrids. Bul. Va. Agr. Exp. Sta. 177:17-53. 1908.

Shull, G. H.
Duplicate genes for capsule form in *Bursa bursa-pastoris*. Zeit. induk. Abst. Vererb. 12:97-149. 1914.

Tschermak, E. von.
Weitere Kreuzungsstudien an Erbsen, Levkojen, und Bohnen. Zeitsch. landw. Versuchsw. Oesterreich. 1904. pp. 1-102.

Bastardierungsversuche an Levkojen, Erbsen, und Bohnen mit Rücksicht auf die Faktorenlehre. Zeit. induk. Abst. Vererb. 7:81-234. 1912.

TABLE 1.—*Frequency distribution of number of internodes per plant in bush-bean races and crosses.*

Race or cross	Pedigree number	Generation	Number of internodes 4	5	6	7	8	Number of individuals	Mean	Standard deviation	Coefficient of variation
Red Marrow	3,457—64	P_1	1	25	51	8	...	85	5.78 ± 0.05	0.62 ± 0.03	10.76 ± 0.57
Triumph	3,413—16	P_1	1	12	58	10	1	82	5.98 ± 0.04	0.60 ± 0.03	10.11 ± 0.53
Red Marrow-Triumph	3,456	F_1	...	2	6	1	...	9	5.89 ± 0.13	0.57 ± 0.09	9.63 ± 1.54
	3,465—71	F_2	2	25	51	15	1	94	5.87 ± 0.05	0.73 ± 0.04	12.48 ± 0.62
July-Triumph[1]	3,483—85	F_2	...	6	12	2	1	21	5.90 ± 0.11	0.75 ± 0.08	12.71 ± 1.34
Snowflake-Triumph[1]	3,448—49	F_2	...	6	5	2	...	13	5.69 ± 0.13	0.72 ± 0.09	12.67 ± 1.71
July-Red Marrow[1]	3,480—82	F_2	...	5	4	7	...	16	6.13 ± 0.14	0.86 ± 0.10	13.98 ± 1.69
Snowflake-Red Marrow[1]	3,450—53	F_2	5	5	6	4	...	20	5.45 ± 0.16	1.07 ± 0.11	19.65 ± 2.18

[1] Bush segregates only. For the pole beans of these F_2 families see Table 2.

TABLE 2.—*Frequency distribution of number of internodes per plant in pole-bean races and crosses.*

Race or cross	Pedigree number	Generation	Class centers for number of internodes											Number of individuals	Mean	Standard deviation	Coefficient of variation
			14	17	20	23	26	29	32	35	38	41	44				
Snowflake	3,425—29	P_1	2	5	8	7	3	..	..	..	..	..	..	25	20.48 ± 0.44	3.36 ± 0.32	16.46 ± 1.61
July	3,431—34	P_1	..	..	2	6	3	10	5	1	1	..	..	28	27.82 ± 0.55	4.34 ± 0.39	15.61 ± 1.42
July-Snowflake	3,435—39	F_1	..	..	1	1	3	4	6	4	1	..	..	20	30.35 ± 0.66	4.40 ± 0.47	14.49 ± 1.58
July-Red Marrow	3,454—55	F_1	..	..	1	3	4	1	2	..	..	..	..	11	26.00 ± 0.74	3.62 ± 0.52	13.92 ± 2.14
Snowflk.-Triumph[1]	3,448—49	F_1	..	..	..	..	1	6	3	3	1	..	..	14	31.36 ± 0.59	3.24 ± 0.41	10.34 ± 1.45
	3,486—88	F_2	..	3	8	8	4	2	3	..	..	..	..	28	23.32 ± 0.54	4.33 ± 0.39	18.57 ± 1.73
Snowflake-Red Marrow[1]	3,450—53	F_1	..	..	1	2	7	5	1	..	..	..	..	16	26.56 ± 0.48	2.85 ± 0.34	10.73 ± 1.29
	3,472—73	F_2	..	3	6	12	19	9	2	4	2	..	1	58	26.31 ± 0.47	5.33 ± 0.33	20.27 ± 1.32

[1] Pole segregates only in the F^2 families. For the bush segregates see Table 1.

TABLE 3.—*Frequency distribution of number of internodes per plant in Longfellow and F_4 of the Longfellow-Fillbasket cross.*

Race or cross	Pedigree number	Generation	Number of internodes					Number of individuals	Mean	Standard deviation	Coefficient of variation
			4	5	6	7	8				
Longfellow	3,247	P	3	13	2	..	..	18	4.94 ± 0.08	0.52 ± 0.06	10.61 ± 1.20
Longfellow-Fillbasket	3,251	F_4	..	4	17	18	2	41	6.44 ± 0.08	0.73 ± 0.05	11.40 ± 0.86
Longfellow-Fillbasket	3,254	F_4	2	26	8	..	..	36	5.17 ± 0.06	0.50 ± 0.04	9.66 ± 0.78

TABLE 4.—*Frequency distribution of mean length of the first five internodes of various races and crosses of beans.*

Race or cross	Pedigree number	Generation	Habit	Class centers in millimeters for internode length: 8	13	18	23	28	33	38	43	48	53	58	63	68	73	Number of individuals	Mean	Standard deviation	Coefficient of variation
Red Marrow	3,457—64	P	D[1]			12	29	28	2									71	24.41 ± 0.31	3.86 ± 0.22	15.81 ± 0.91
Triumph	3,413—16	P	D	5	51	19	3											78	14.28 ± 0.24	3.15 ± 0.17	22.06 ± 1.25
Snowflake	3,425—29	P	I[1]		1	13	34	9	1									58	22.65 ± 0.32	3.58 ± 0.22	15.81 ± 1.01
July	3,431—34	P	I		5	5	14	18	11	14	3	1	1	1	1			74	30.09 ± 0.77	9.83 ± 0.54	32.67 ± 2.64
Red Marrow-Triumph	3,456	F_1	D			2	4	1										7	22.29 ± 0.81	3.19 ± 0.58	14.31 ± 2.63
	3,465—69	F_2	D	1	12	36	18	5	3									75	19.53 ± 0.39	4.97 ± 0.27	25.43 ± 1.49
July-Snowflake	3,435—39	F_1	I		2	8	18	2	1									31	21.71 ± 0.49	4.01 ± 0.34	18.47 ± 1.63
	3,489—91	F_2	I		2	11	18	26	8	1	3	1						70	26.36 ± 0.54	6.75 ± 0.38	25.61 ± 1.55
July-Triumph	3,483—85	F_2	I		1	14	14	16	2	2	1	1						51	24.86 ± 0.64	6.78 ± 0.45	27.27 ± 1.95
			D			2	4	6	4		1							17	27.71 ± 0.99	6.06 ± 0.70	21.87 ± 2.65
July-Red Marrow	3,454—55	F_1	I				1	2	4	4	1							12	33.83 ± 1.04	5.34 ± 0.74	15.78 ± 2.22
	3,480—82	F_2	I			4	12	10	16	6	3		4			1	1	57	32.74 ± 1.01	11.26 ± 0.71	34.39 ± 2.42
			D				4	1	3	1	2				1			12	33.83 ± 2.21	11.33 ± 1.56	33.49 ± 5.10
Snowflake-Triumph	3,448—49	F_1	I			2	9	3	1									15	24.00 ± 0.65	3.74 ± 0.46	15.58 ± 1.97
	3,486—88	F_2	I		1	17	30	3										51	21.43 ± 0.29	3.05 ± 0.20	14.23 ± 0.97
			D		1	3	3	3	2	4								16	27.38 ± 1.36	8.08 ± 0.96	29.51 ± 3.82
Snowflake-Red Marrow	3,450—53	F_1	I			2	4	5	4	1								16	27.37 ± 0.94	5.56 ± 0.66	20.32 ± 2.52
	3,472—73	F_2	I		3	11	21	15	8		3	4	1					66	26.94 ± 0.75	8.98 ± 0.53	33.33 ± 2.16
			D				2	7	3	2		2						16	32.06 ± 1.24	7.33 ± 0.87	22.86 ± 2.86

[1] D—determinate, I— indeterminate.

TABLE 5. *Frequency distribution of mean length of the first 15 internodes of various races and crosses of beans.*

Race or cross	Pedigree number	Generation	Class centers in millimeters for internode length									Number of individuals	Mean	Standard deviation	Coefficient of variation
			23	38	53	68	83	98	113	128	143				
Snowflake	3,425 29	P	5	25	19	9						58	46.28 ± 1.13	12.81 ± 0.80	27.68 ± 1.86
July	3,431 34	P			8	14	20	11	13	6	2	74	89.69 ± 1.84	23.41 ± 1.30	26.11 ± 1.52
July-Snowflake	3,435—39	F_1	1	3	13	13	1					31	57.84 ± 1.49	12.27 ± 1.05	21.20 ± 1.90
	3,489 91	F_2	1	8	19	21	11	3	2	4	1	70	69.29 ± 1.99	24.68 ± 1.41	36.90 ± 2.37
July-Triumph	3,483 85	F_2		8	12	14	9	3	4	1		51	68.88 ± 2.14	22.71 ± 1.52	32.97 ± 2.43
July-Red Marrow	3,454 55	F_1				1	1	7	3			12	98.00 ± 2.39	12.25 ± 1.69	12.50 ± 1.75
	3,480 82	F_2		2	16	15	14	4	4	1	1	57	74.05 ± 1.96	21.92 ± 1.39	29.62 ± 2.03
Snowflake-Triumph	3,448 49	F_1			2	11	2					15	68.00 ± 1.35	7.75 ± 0.95	11.40 ± 1.42
	3,486—88	F_2	11	26	13	1						51	39.18 ± 1.04	11.05 ± 0.74	28.20 ± 2.02
Snowflake-Red Marrow	3,450 53	F_1		1	7	8						16	59.56 ± 1.54	9.14 ± 1.09	15.35 ± 1.87
	3,472 73	F_2	2	17	26	10	9	1	1			66	56.18 ± 1.48	17.83 ± 1.05	31.74 ± 2.02

TABLE 6.—*Frequency distribution of mean length of the first five internodes of the parents and* F_1 *of the Snowflake-Tallbush cross, grown in the garden in 1912.*

Race or cross	Pedigree number	Generation	Habit	Class centers in millimeters for internode length: 13	18	23	28	33	38	43	48	53	No. of individuals	Mean	Standard deviation	Coefficient of variation
Snowflake	3,425—29	P	I	1	13	34	9	1	..	..	..	..	58	22.65 ± 0.32	3.58 ± 0.22	15.81 ± 1.01
Tallbush	3,420	P	D	..	..	..	..	1	3	6	3	4	17	44.76 ± 0.93	5.71 ± 0.59	12.76 ± 1.50
Snowflake-Tallbush	3,440—43	F_1	I	..	..	8	12	10	3	1	..	..	34	29.62 ± 0.59	5.10 ± 0.42	17.23 ± 1.45

TABLE 7.—*Frequency distribution of mean length of the first five internodes of the F_2 generation of the Snowflake-Tallbush cross grown in the greenhouse in the winter of 1912-1913.*

Race or cross	Pedigree number	Generation	Habit	Class centers in millimeters for internode length																					Number of individuals	Mean
				18	23	28	33	38	43	48	53	58	63	68	73	78	83	88	93	98	103	108	113	118		
Snowflake	3,958	P	I		3	1																			4	(24)
Tallbush	3,957	P	D													1	1				2			1	5	(97)
Snowflake-Tallbush	3,959	F_1	I							1															1	(48)
	3,961	F_2	I	1	2	5	9	17	9	6	9	10	5	7	1	2	1	1	1				1	1	88	49.82
			D			1	3	3	1	10	3	3	1	2	1		2			1					31	52.68

TABLE 8.—*Frequency distribution of height of plants of the* F_2 *generation of the Snowflake-Tallbush cross, grown in the greenhouse in the winter of 1912-1913.*

Race or cross	Pedigree number	Generation	Habit	Class centers in centimeters for height of plant																			Number of individuals	Means
				15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195		
Snowflake	3,958	P	I					2	1	1													4	(62.5)
Tallbush	3,957	P	D				1	1	1	2													5	(63)
Snowflake-Tallbush	3,959	F_1	I														1						1	(145)
	3,961	F_2	I			5	8	9	9	12	7	7	6	4	10	4	3	1		1	1	1	88	88.64
			D	2	14	10	3	2															31	31.45

(7-29-15-4M.)

RESEARCH BULLETIN NO. 8.

THE UNIVERSITY OF NEBRASKA.

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA.

THE COLLOIDAL SWELLING OF WHEAT GLUTEN IN RELATION TO MILLING AND BAKING.

BY F. W. UPSON AND J. W. CALVIN.

DISTRIBUTED JUNE 30, 1916

LINCOLN, NEBRASKA
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THE COLLOIDAL SWELLING OF WHEAT GLUTEN IN RELATION TO MILLING AND BAKING.

BY FRED W. UPSON AND JOHN W. CALVIN.

Aside from its theoretical interest in connection with the general problem of water absorption by animal and plant tissues, the colloidal swelling of gluten is of great practical importance in its relation to certain problems of milling and baking. In a former paper[1] the authors have presented experiments on the colloidal hydration of moist wheat gluten and discussed the subject of water absorption in its theoretical aspects. This subject has also been dealt with in papers by Wood[2] and by Wood and Hardy.[3]

A review of the literature on wheat and flour chemistry shows that, excepting the work of the authors named, the colloidal properties of gluten have not been taken into account in previous investigations in this field. This subject is far too important to be overlooked.

The experiments by Wood and by Wood and Hardy were carried out by immersing small bits of gluten, suspended over glass rods, in beakers containing solutions of varying concentrations of different acids both with and without the presence of salts, and noting the effect of the different solutions in bringing about "disintegration" and "loss of cohesiveness" of the gluten. Our experiments deal with the changes in *hydration capacity* of gluten under different conditions and were carried out by determining accurately the amount of water absorbed by gluten from solutions of varying concentrations of different acids, both with and without the presence of salts.

EXPERIMENTS ON THE SWELLING OF WHEAT GLUTEN.[4]

The gluten for the following experiments was prepared by washing the starch from flour under a stream of distilled water.

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[1]Upson and Calvin, Jour. Amer. Chem. Soc. 37, 1295 (1915).

[2]Wood, Jour. Agr. Sci. 2, 267 (1907).

[3]Wood and Hardy, Proc. Roy. Soc. London, (B) 81, 38 (1909).

[4]For a brief bibliography of work on the colloidal swelling of proteins see article by the authors, Jour. Amer. Chem. Soc. 37, 1295 (1915).

For a detailed account of experiments on the swelling of animal proteins see Fischer, Oedema and Nephritis, Sec. Ed. N. Y. (1915).

We found the character of the gluten to be quite different when tap water, which contains salts, was used in place of distilled water, being tougher and more elastic, just as pointed out by Wood and Hardy.[5] Since we wished to avoid the effect of any salts which might be absorbed by the gluten from the tap water, all samples of gluten were prepared with distilled water. The gluten ball was pressed out between glass plates to a fairly uniform thickness. After standing some time between the plates (during which time some fluid was usually squeezed off), disks could be cut from the gluten with a large cork borer, which were fairly uniform as to surface and weight. The disks were weighed to the nearest centigram and placed in the solution for exactly 2 hours, whereupon they were removed, drained on a Buchner funnel, and weighed again. The method is necessarily somewhat crude, because the gluten is moist when weighed originally and because of the variation in the amount of water which mechanically adheres to the disks. Nevertheless, when the average of a number of determinations is taken the results are surprisingly uniform.

TABLE 1.—*Lactic acid.*

Conc. of acid	Wt. of water absorbed in g. per g. of moist gluten				Average
	A	B	C	D	
None	0.046	....	0.075	0.043	0.055
0.002 *N*	1.30	1.31	1.02	1.07	1.18
0.005 *N*	1.42	1.54	1.35	1.55	1.46
0.01 *N*	1.51	1.77	1.44	1.55	1.57
0.02 *N*	1.60	1.55	1.53	1.61	1.57
0.04 *N*	1.48	1.51	1.35	1.42	1.44
0.1 *N*	1.37	1.38	1.07	1.28	1.27
0.2 *N*	1.23	1.15	1.11	1.19	1.15
0.5 *N*	1.01	Lost	0.99	1.08	1.03

[5]Wood and Hardy, Proc. Roy. Soc. London, (B) 81, 38 (1909).

TABLE 2.—*Acetic acid.*

Conc. of acid	Wt. of water absorbed in g. per g. of moist gluten			Average
	A	B	C	
None	0.03	0.01	—0.03	0.01
0.002 *N*	1.11	1.47	1.30	1.29
0.005 *N*	1.39	1.58	1.90	1.62
0.01 *N*	1.43	1.58	1.87	1.63
0.02 *N*	1.56	1.76	1.96	1.76
0.04 *N*	1.80	1.88	2.03	1.90
0.1 *N*	1.62	2.06	1.86	1.85
0.2 *N*	1.51	1.82	1.76	1.69
0.5 *N*	1.49	1.69	1.66	1.61

TABLE 3.—*Hydrochloric acid.*

Conc. of acid	Wt. of water absorbed in g. per g. of moist gluten		Average
	A	B	
None	0.00	0.00	0.00
0.002 *N*	1.47	1.28	1.37
0.005 *N*	1.63	1.44	1.54
0.01 *N*	1.67	1.37	1.52
0.02 *N*	1.37	1.12	1.23
0.04 *N*	0.83	0.68	0.75
0.1 *N*	0.14	0.16	0.15
0.2 *N*	—0.097	0.01	—0.04
0.5 *N*	—0.19	—0.09	—0.14

The curves showing the amount of water absorption with increasing concentration of acid for Tables 1, 2, and 3 are shown in Figure 1. The curves represent the average for four, three, and two determinations, respectively, for lactic, acetic, and hydrochloric acids. The concentrations of acid are plotted along the horizontal, and the water absorption in grams per gram of moist gluten is plotted on the vertical axis. An inspection of these curves brings out some interesting facts. For hydrochloric acid the maximum absorption is obtained with a concentration of 0.005 *N*, while the concentration for maximum absorption with lactic acid lies between 0.01 *N* and 0.02 *N* and for acetic acid is 0.04 *N*. It is to be noted that for concentrations above the one for maximum absorption, the curves do not fall off at anything like the same rate for the three acids. The curve for hydrochloric falls much more rapidly than the curves for the other

two. This agrees with the results as found by Fischer[6] for fibrin and by Ostwald for gelatin.[7] Fischer obtained maximum swelling of both fibrin and gelatin in approximately 0.025 *N* hydrochloric acid and diminished swelling for concentration above this.

Of special interest is the fact that both lactic and acetic acids show concentrations of optimal swelling for gluten. Such an optimal swelling of a protein in a "weak" acid has never before been observed. It does not occur in gelatin, fibrin, and the other animal colloids thus far studied. The swelling of gluten also diminishes much more rapidly with increasing concentration of hydrochloric acid beyond the optimal point than does the swelling of gelatin or fibrin. It is also of interest that moist gluten *loses* water in the higher concentrations of hydrochloric acid, 0.2 *N* and 0.5 *N*. We have established that gluten disks lose weight in these higher concentrations of acid because of loss of water and not because of "solution" of the gluten. Examination of the surrounding fluids in these higher concentrations of acid fails to reveal more than traces of dissolved protein, whereas in the lower concentrations where greatest swelling takes place considerably more protein is dissolved. When gluten swells in dilute acid the disks puff up and take on an appearance somewhat resembling cotton balls, finally becoming transparent, soft, and gelatinous. In 0.2 *N* and 0.5 *N* hydrochloric acid, the disks do not change in appearance or in physical properties except to become tougher and more elastic just as in salt solutions. Disks which have lost water in 0.5 *N* hydrochloric acid gain water and become soft and gelatinous when placed in more dilute acid. Those which have absorbed water to more than double their weight in the more dilute acid lose it if placed in 0.5 *N* acid. The taking up and giving off of water is, in other words, largely reversible.

When any salt is added to an acid in which a gluten disk is swelling, the swelling is much reduced. This is shown in Table 4 and Figure 2, which is based upon the results shown in this table.

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[6] Fischer, Oedema and Nephritis, Sec. Ed., N. Y. (1915), pp. 44, 48.
[7] Ostwald, Pflüger's Arch., 108, 577 (1905).

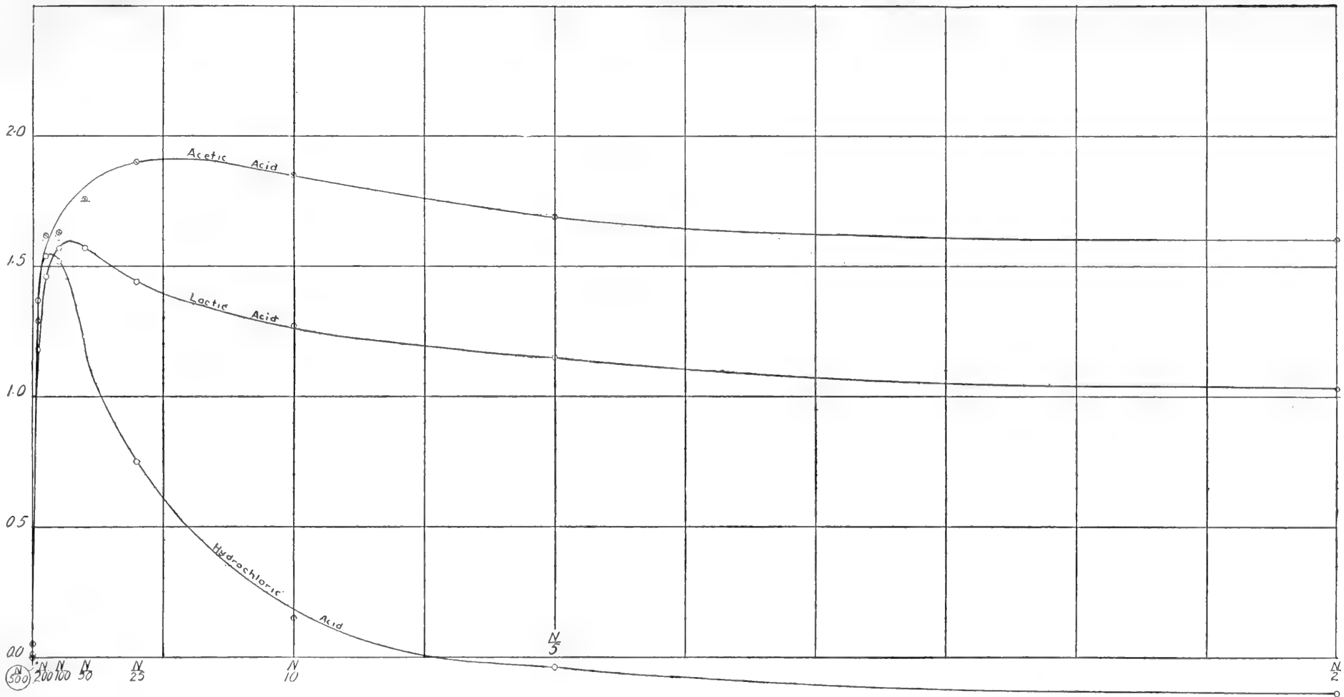


Fig. 1.—Water absorption by gluten in different concentrations of different acids.

TABLE 4.—*0.005 M salt solutions and varying concentrations of lactic acid.*

Conc. of acid solution	Wt. of water absorbed in g. per g. of moist gluten				
	0.005 *M* $K_2C_4H_4O_6$	0.005 *M* K_2HPO_4	0.005 *M* KCl	0.005 *M* $CaCl_2$	No salt
No acid	—0.11	—0.14	—0.11	—0.11	—0.01
0.002 *N*	—0.06	—0.012	0.49	0.25	1.39
0.005 *N*	0.04	0.16	0.77	0.42	1.50
0.01 *N*	0.25	0.63	0.98	0.57	1.81
0.02 *N*	0.55	0.86	1.28	0.68	1.87
0.04 *N*	0.73	0.97	1.30	0.89	1.72
0.1 *N*	1.06	1.12	1.43	0.96	1.69

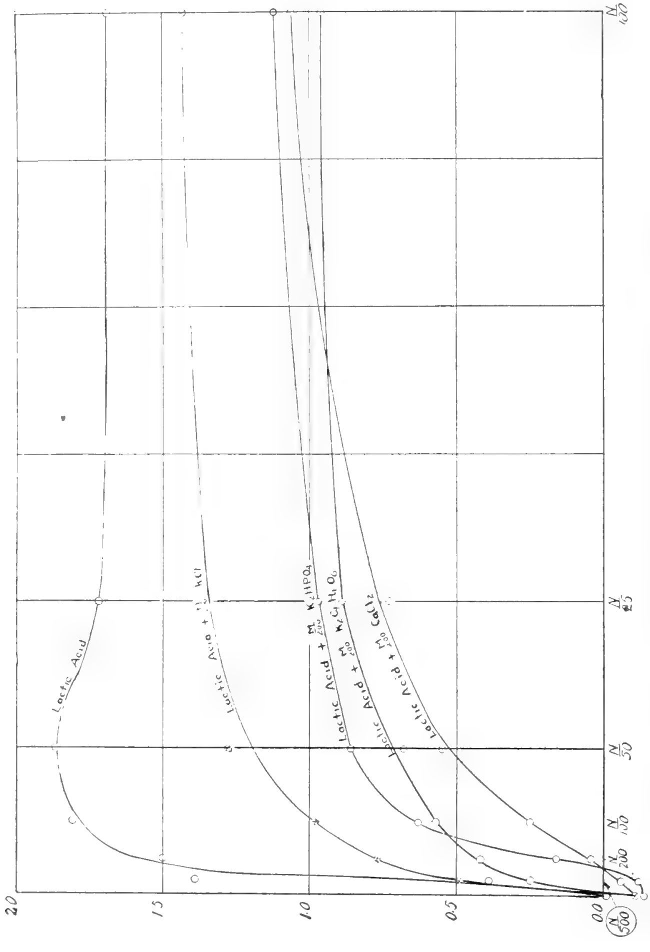


Fig. 2.—Effect of $M/200$ concentrations of different salts in reducing swelling of gluten in lactic acid solutions.

In Table 5 are given the figures showing the effect of varying concentrations of four salts and also of glycocoll on the absorption of water by gluten in the presence of 0.01 *N* lactic acid. The results are shown graphically in Figure 3.

In all cases there is a rapid decrease in water absorption with an increase in the concentration of the salt. In the higher concentrations of phosphate and tartrate, the gluten disk drops to a weight below that of the original moist disk.

TABLE 5.—*0.01 N lactic acid and varying concentrations of salts and of glycocoll.*

Conc. of salt solution	Wt. of water absorbed in g. per g. of moist gluten 0.01 *N* lactic acid and				
	KCl	K_2HPO_4	$K_2C_4H_4O_6$	$CaCl_2$	Glycocoll
No salt	1.70	2.12	1.87	2.02	1.70
0.001 *M*	1.23	1.17	1.18	1.50	....
0.002 *M*	1.09	0.85	0.85	1.21	1.57
0.005 *M*	0.74	0.49	0.26	0.85	1.65
0.01 *M*	0.46	0.06	—0.02	0.43	1.29
0.02 *M*	0.21	—0.18	—0.11	0.11	1.21
0.04 *M*	—0.03	—0.21	—0.14	0.00	1.14
0.1 *M*	....	....	....	....	0.71
0.2 *M*	....	....	....	....	0.53
0.4 *M*	....	....	....	....	0.50

At the concentration of 0.02 *M* the order of salts as regards their effect in diminishing absorption is the same as found by Fischer for gelatin and fibrin, namely: Chloride, tartrate, and phosphate. That the relative position of the curves for the four salts is not the same for all concentrations may or may not be significant. We do not think the matter due to experimental error. There is undoubtedly a very important relation between the exact concentration of the acid and the inhibiting effect at different concentrations of the salts. Of special interest is the fact that glycocoll behaves like a salt in reducing the swelling of gluten in acid solution. The effect, however, is less marked than with the different salts studied.

A series of photographs will help to make evident the significant differences in the swelling of gluten under different conditions.

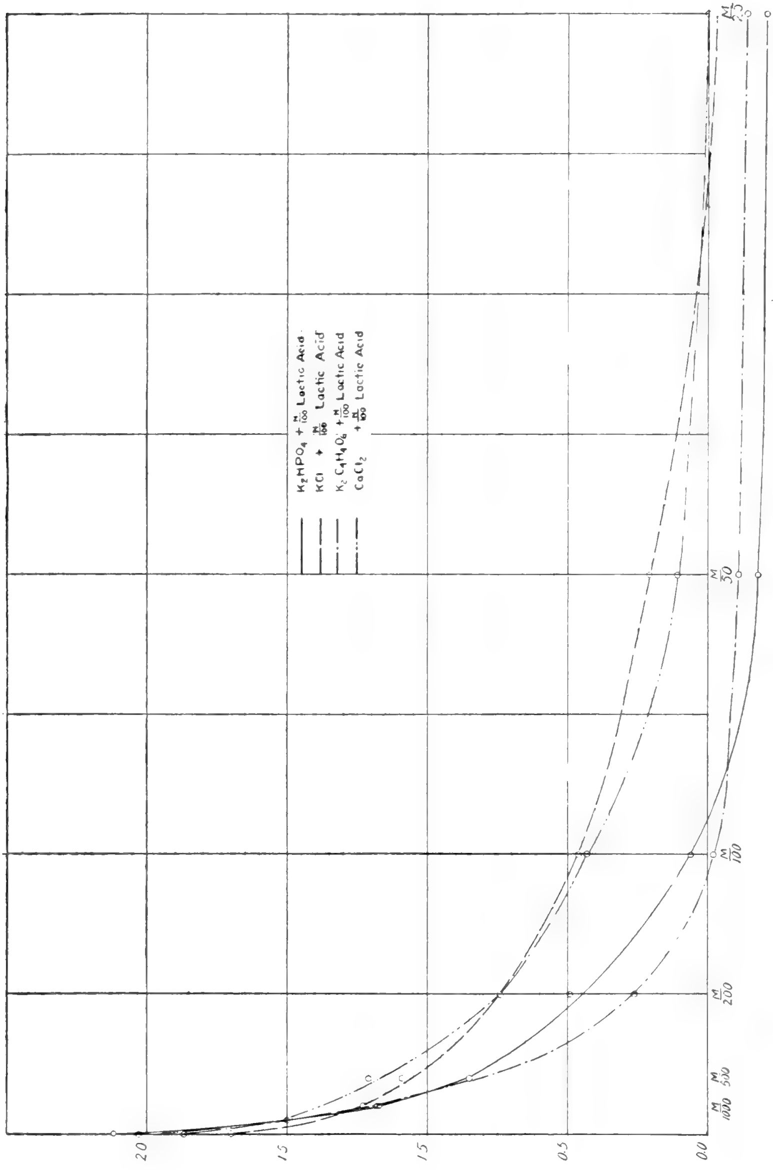
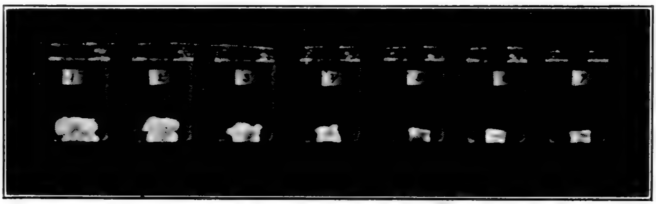


Fig. 3.—Effect of varying concentrations of different salts in reducing swelling of gluten in $M/100$ lactic acid.

H_2O $N/500$ $N/200$ $N/100$ $N/50$ $N/25$ $N/10$

Fig. 4.—The lactic acid series (A) of Table 1. Beaker 1 contains distilled water. Beakers 2 to 7 contain lactic acid in concentrations from 0.002 N to 0.1 N as shown in Table 1. The difference in size of the disks in distilled water and in the different concentrations of acid is plainly evident.

Figure 5 shows a 0.01 N lactic acid series, to which have been added varying concentrations of K_2HPO_4 as in Table 5. Beaker 1 contains 0.01 N lactic acid. Beakers 2 to 7 contain 0.01 N lactic acid with K_2HPO_4 varying in concentration from 0.001 M to 0.4 M. The increasing antagonistic effect of the salt with increasing concentration is very apparent.



Acid   M/1000   M/500   M/200   M/100   M/60   M/25

Fig. 5.—N/100 lactic acid with increasing K_2HPO_4 solution.

TABLE 6.—*Reversibility of water absorption by gluten.*

A Original wt. of disks		B Wt. of disks after 2 hrs. in acid		Conc. of acid	C Wt. of disks after transference to 0.1 N K_2HPO_4 for 1 hr.	
A	B	A	B		A	B
1.39	1.23	1.41	1.20	No acid	1.14	0.95
1.30	1.26	3.21	2.89	0.002 N	1.18	1.16
1.33	1.22	3.43	3.54	0.005 N	1.22	1.10
1.39	1.28	3.57	3.67	0.01 N	1.27	1.17
1.42	1.24	3.92	3.67	0.02 N	1.30	1.14
1.29	1.27	3.90	3.85	0.04 N	1.17	1.15
1.29	1.29	3.95	3.69	0.1 N	1.21	1.24
1.31	1.29	3.69	3.56	0.2 N	1.28	1.26
1.31	1.30	3.52	3.46	0.5 N	1.35	1.35

Table 6 shows the reversible nature of water absorption by gluten. There are shown in Column A the original weights of two series of gluten disks, and in Column B their weights after remaining two hours in acetic acid solutions varying from 0.002 N to 0.5 N. In Column C are given the weights of the same disks after remaining one hour in 0.1 N dipotassium phosphate solution. These experiments show how the disks, after taking up water in the acid solutions to twice their original weight or more, give up the water in the salt solution. Not only do they reassume their original weight, but their original appearance and physical properties, as toughness and elasticity, as well.

TABLE 7.—*Effect of temperature on water absorption.*

Solution	Wt. of water absorbed in g. per g. of moist gluten	
	24°	39°
In water	0.06	0.09
In 0.01 N HCl	1.47	2.01
In 0.01 N lactic	1.65	2.66
In 0.01 N acetic	1.68	2.79

Table 7 is introduced to show the effect of temperature on the absorption of water by gluten. It shows that in acid solutions the higher the temperature the more the gluten swells.

TABLE 8.—*0.01 N lactic acid with varying amounts of flour and bran extracts.*

0.01 N lactic acid cont. extract from flour	Water abs. in g. per g. of moist gluten	0.01 N lactic acid cont. extract from bran	Water abs. in g. per g. of moist gluten
No extract	2.23	No extract	1.48
0.625 g. per 100 cc.	2.16	0.625 g. per 100 cc.	1.12
1.25 g. per 100 cc.	1.81	1.25 g. per 100 cc.	1.02
2.50 g. per 100 cc.	1.47	1.87 g. per 100 cc.	0.91
5.00 g. per 100 cc.	1.25	2.50 g. per 100 cc.	0.82
		4.75 g. per 100 cc.	0.33

TABLE 9.—*0.01 N lactic acid with varying amounts of cane sugar.*

Conc. of sugar solution	Water abs. in g. per g. of moist gluten
None	1.75
0.1 M	1.41
0.2 M	1.54
0.5 M	1.42
1.0 M	0.71
1.5 M	0.28

Table 8 shows that water extracts of flour and bran reduce the swelling of gluten in acid solutions. Their effect is similar to, tho not as marked as, the effect of neutral salts.

Table 9 shows that nonelectrolytes such as cane sugar are comparatively ineffective in reducing the swelling of gluten in acid solutions except in high concentrations. Fischer finds the same for gelatin and sugar solutions.

DISCUSSION.

The experiments described show that the mixture of vegetable proteins which comprises wheat gluten behaves in a manner entirely analogous to the animal proteins as studied by Fischer and others. Moist gluten absorbs water from acid solutions, and the amount of absorption varies with the kind and concentration of the acid. The strong acids are most effective in bringing about water absorption in dilute solution. Maximum absorption is attained with 0.01 N (0.036 per cent) hydrochloric acid. As the concentration increases above this point, water absorption becomes less and less until at a concentration of 0.1 N (0.36 per cent) no absorption takes place. The weaker acids, lactic and acetic, show also concentrations of optimal swelling.

But for concentrations above the optimum, swelling does not fall off at the same rate as in the case of hydrochloric acid. The presence of neutral salts in the acid solution reduces water absorption, the absorption becoming less and less as the concentration of salt increases till at a concentration of approximately 0.05 *M*, absorption is entirely prevented. For varying concentrations of any one salt and acid, the concentration of salt necessary to prevent swelling of gluten first rises and then falls, with increasing concentration of the acid. Gluten which has absorbed water in acid solution and taken on a soft, jellylike consistency loses water and regains its original physical properties when placed in a salt solution.

Acids and salts therefore determine not only the physical properties of gluten but its water-holding capacity as well. Gluten prepared by washing flour in many changes of tap water is an elastic, rubberlike mass, possessing tenacity. When placed in dilute acid solutions, gluten absorbs water, at the same time losing its tenacity and elasticity, becoming soft and gelatinous. Wood and Hardy[8] have arrived at the same conclusions thru a study of the dispersion and "loss of cohesiveness" of gluten in different solutions, by methods quite different from ours.

The relation of physical properties of gluten to "strength" in flour has been considered in papers by Wood[9] and Hardy.[10] After showing that the properties of gluten depend on the nature and concentration of the acid and salts in the solution with which it is in contact, Wood suggests that "these properties have an important bearing on the shape of the loaf and that a knowledge of the acidity and soluble salt content of a flour gives a clue to the factor of strength which decides whether the flour will make a good shaped loaf." Hardy discusses the work of Wood and points out the importance of the acids and salts in determining the physical properties of the gluten and any other colloids present in the dough.

Numerous attempts have been made in the past to correlate baking strength of flour with various more or less easily determined physical or chemical factors.[11] Some of the factors which have been suggested as bearing a relation to baking strength are total nitrogen, total gluten, total gliadin, ratio of gliadin to glutenin, ratio of gliadin to total nitrogen, ratio of water soluble nitrogen

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[8]Wood, Jour. Agr. Sci. 2, 267 (1907).
Wood and Hardy, Proc. Roy. Soc. London (B) 81, 38 (1909).

[9]Wood, loc. cit.

[10]Hardy, Jour. Board Agr. Supp. England 17, 52.

[11]For an historical account of the work on baking strength see Blish, Jour. Ind. Eng. Chem. 8, 138 (1916).

to total nitrogen, chemical composition of the individual proteins, ratio of wet to dry gluten, total amount of gas evolved during fermentation, and many others. In spite of the enormous amount of work on this subject carried out by many investigators, no one has yet succeeded in showing that any single physical or chemical factor bears a definite and constant relation to baking strength. Moreover, there is, at present, no unanimity of opinion among investigators as to the importance which should be attached to the different factors in their relation to baking strength.

It now seems certain in the light of our experiments as well as those of Wood and Hardy that the colloidal properties of gluten are of far greater importance in this connection than is generally supposed; and that baking strength in wheat flour is to be associated with *quality* of gluten, which is, in turn, regulated by the kind and concentration of the soluble acids and salts present in the flour or added in the baking process. *Quality* of gluten, as washed from flour in the ordinary method, will depend first on the kind and concentration of the acids and salts present in the flour, and secondly upon the nature of the liquid with which the gluten is washed. If the kind and concentration of the acids and salts in the flour are such as to produce the "acid effect," that is, to favor water absorption, then the gluten will be soft and gelatinous,—in other words will be a "weak" gluten. If the kind and concentration of the acids and salts in the flour are such as to produce the "salt effect," that is, to prevent water absorption, then the gluten will be coherent and tenacious,—in other words, will be a "strong" gluten. Furthermore, as we shall show in the next section of this paper, the character of the gluten may be modified at will, depending on the character of the solution used for washing the starch from the flour. Dilute salt solutions and tap water give a gluten somewhat tougher and more elastic than does distilled water. Distilled water containing carbon dioxide gives a poorer quality of gluten than freshly boiled distilled water. Dilute acid solutions give a soft, gelatinous gluten. If acid solutions of such concentration as give maximum water absorption are used for washing the starch from flour, then it is practically impossible to obtain a gluten ball. The gluten is not destroyed but is simply rendered incapable of being collected.

The now generally accepted definition of baking strength in wheat flour is that suggested by Humphries and Biffin, namely, "the capacity for making large, shapely, and therefore well-aerated loaves." The power which dough made from wheat flour possesses, of retaining the bubbles of carbon dioxide formed during the fermentation, is due to the peculiar qualities of the

gluten. The protein complex of wheat flour, unlike the proteins of other grains, possesses tenacity and elasticity and hence confers on the dough its active mechanical properties. The gluten serves as the cement which holds the starch grains together. Hence, the property of forming large, shapely loaves which varies within wide limits for different flours is dependent on the quantity and the physical state of the contained gluten. Gluten content alone can no longer be considered as an absolute measure of strength. Rather is strength related to quality of gluten which in turn is regulated by the kind and concentration of the acids and salts present in the dough. From the experiments we are justified in concluding that strength is related to soluble acid and salt content of the flour. Flours containing acids and salts in such combinations as to favor water absorption will behave as "weak" flours, whereas those containing acids and salts in such combinations as inhibit water absorption will behave as "strong" flours when baked. Not only will the acids and salts already present in the flour affect the gluten, but any substances added when the flour is made into dough, as well as any acids developed in the fermentation process, will also produce their effect in modifying the gluten.

The authors cannot agree with certain conclusions of Wood. Wood believes that the acids and salts in the wheat grain produce their effect in modifying the character of the gluten at an early stage, probably at the time the endosperm is being formed, when the grain contains more water than it does at the time it is ready to grind.[12] It does not seem to us necessary to suppose, as does Wood, that acids and salts present must produce their effect previous to the time the flour is made into dough. Any substances influencing water absorption by gluten will produce their effect whenever water is added in the doughing process.

Our experiments show that gluten may double in weight thru water absorption in less than 1 hour, at the same time losing its tenacity and elasticity. Wood found that gluten requires about 48 hours to come into equilibrium with its surroundings.[13] From this he erroneously concludes that it would not be possible to test the effect of the addition of acids, alkalies, and salts in modifying the baking qualities of flour, since the acid, alkali, or salt would have to be added some 40 hours before the doughing process is begun. Since, as we find, gluten may be greatly modified as to physical properties by acids, alkalies, or salts in so short a time as 1 hour, it ought to be perfectly practicable to

[12]Wood, Jour. Agr. Sci. 2, 274 (1907).
[13]Wood, Jour. Agr. Sci. 2, 273 (1907).

test the effect of these substances in modifying the qualities of the gluten. (It is the intention of the authors to carry out in the near future detailed studies of this character.)

Recent work on the effect of the addition of various substances to dough on the bread-making qualities of flour is of interest in this connection. White[14] has investigated the effect of the addition of bran extracts to the dough on the quality of loaf obtained. He made experiments, adding water, extract of bran, 0.2 per cent hydrochloric acid extract of bran, and 0.2 per cent acid alone. The dilute acid gave a loaf smaller in volume than the check and of very poor texture. The water and acid extracts of bran gave improved loaves. Acid extracts neutralized with alkali gave a poorer loaf than the check.

Willard and Swanson[15] have determined the effect of a number of substances on the baking qualities of flour. They found that glycocoll and several other amino acids produced marked detrimental effects. Salts showed either no marked effects or a beneficial one. Ammonium chloride in small amounts affected the baking qualities of flour favorably. Sodium carbonate was markedly detrimental. Extracts of various milling by-products gave improved loaves of bread for the most part. Neither White nor Willard and Swanson offer any explanation of their interesting results. Willard and Swanson make the following statement: "That the baking qualities of flour bear an intimate relation to chemical substances that may naturally be present, or that may be produced from normal constituents of the flour or introduced thru imperfect milling, is beyond question." In our opinion the explanation of the results of White and of Willard and Swanson is to be found in the effect which the added substances produced in altering the hydration capacity of the gluten.

Freed[16] has investigated the effect of the addition of varying quantities of salt to the dough on the character of loaf obtained. He found that the size and texture of the loaf, as well as the time of fermentation, varied with the amount of salt used. The length of time required for fermentation increased regularly with increase in amount of salt added. The volume of loaf increased with increase of salt up to 3 pounds of salt per 196 pounds of flour; with increasing amounts of salt above this the volume decreased. The texture of the bread was best in the loaf having greatest volume and poorest in the bread in which no salt was used. Where more than 3 pounds of salt for 196 pounds of flour was used the loaf was of smaller volume and poorer in texture.

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[14]White, Jour. Ind. Eng. Chem. 5, 990 (1913).
[15]Willard and Swanson, Kansas Agr. Exp. Sta. Bul. 190 (1913).
[16]Freed, Oper. Miller, 18, 794 (1913).

These results are entirely in harmony with our conclusions. Increasing amounts of salt, up to a certain point, render the gluten tougher and tougher and hence lengthen the time of fermentation. It is probable that the salt controls the time of fermentation as well as the size and texture of the loaf thru its effect in modifying the physical character of the gluten, rather than thru its effect in controlling the chemical changes, as suggested by Freed. Bread made without salt is of poor texture, because, in the absence of salt, the gluten is soft and without elasticity and tenacity. Increase of temperature favors water absorption by the gluten. Higher temperatures also favor the production of lactic acid. More salt is needed therefore in warm weather to overcome the effect of these factors in causing the gluten to absorb water and so become soft and gelatinous.

There is, without doubt, an optimum degree of toughness of gluten for the best results in bread making. Too tough a gluten may inhibit proper expansion of the dough, while too soft a gluten will permit the gas bubbles to break, producing a loaf of small size and inferior texture. It is thus to be expected that flours of widely different baking strength would not respond in the same manner to the same treatment. Treatment which would give favorable results with a "strong" flour, that is, the addition of some substance which favors water absorption by gluten, would give unfavorable results with a "weak" flour. "Weak" flours require treatment which will reduce the water-holding capacity of the gluten, such as the addition of neutral salts. These facts are sufficient to account for the conflicting results obtained by different investigators on the effect of the addition of different substances to flour in the baking process.

Wahl[17] has recently presented conclusions gained from a study of the effect of lactic acid when added to the dough in the bread-making process. No experimental data are given. He makes the statement that bacterial lactic acid produced by propagating *Bacillus Delbruecki* on media such as bran mash, crushed wheat, flours, stale bread, and the like, improves the quality of bread, and is more effective in this respect than commercial lactic acid. The effect of the various substances on the physical properties of gluten is not taken into account. From our results it is clear that acid solutions alone will not produce the same effect in modifying the gluten as acid solutions containing the extractives of bran or flour.

Kohman et al.[18] have recently taken out patents on formulas

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[17]Wahl, Jour. Ind. Eng. Chem. 7, 773 (1915).

[18]Kohman et al. Chem. Abs. 9, 2,784 (1915); 10, 232; 233 (1916).

for salt mixtures for use in bread making. These mixtures contain ammonium chloride and calcium sulphate. It is stated that these substances are of value in that they effect a saving in yeast, promote its growth, etc. While these substances may promote the growth of the yeast plant, they also certainly change the physical character of the gluten. Their effect in modifying the character of the gluten must be taken into account in explaining their action.

It seems probable also that the beneficial results obtained from the use of mineral "flour improvers" depend in part at least on the effect produced by these substances in modifying the physical properties of the gluten. These improvers usually contain phosphates, which are among the most effective substances in inhibiting water absorption by gluten. Most pronounced results are obtained with the use of these improvers on weak flours such as are grown in the British Isles. These flours have been shown to be exceptionally low in content of soluble salts and especially in phosphates.

EXPERIMENTS ON THE WASHING OF GLUTEN.

METHODS FOR THE DETERMINATION OF WET GLUTEN.

Experiments were carried out on the washing of gluten from flour using various solutions as well as distilled water and tap water. The solutions used were sodium chloride of several different concentrations, potassium phosphate, dilute hydrochloric acid, magnesium chloride, and hydrochloric acid in combination with sodium chloride.

The method employed for washing the starch from the gluten was in all cases the same. Ten grams of the flour were weighed out and made into a stiff dough in a round-bottomed porcelain cup. The cup was then filled with water or solution and allowed to stand for exactly one hour. In the case of all of the flours except the low grade, 6 cc. of liquid were used in making the dough; in the case of the latter, 6.5 cc. were used. After being allowed to stand under the liquid for one hour the ball of dough was carefully worked under a stream of the solution or water for exactly 14 minutes. It was then removed from under the stream and worked in the fingers for 1 minute, placed on a tared dish, and weighed. This weight was recorded as the weight of wet gluten. The mass was then dried to constant weight at 110° C. and again weighed; this was recorded as the weight of dry gluten. In all cases, unless otherwise stated, the solution in which the gluten was to be washed was used in making up the dough and was placed over it while standing. Care was taken

to keep the solution at a constant temperature, which was recorded.

In Table 10 are recorded the percentages of wet gluten, of dry gluten, and of actual protein obtained from 10 grams of flour. Nitrogen in the dried gluten was determined by the Kjeldahl method. The figure for protein was obtained from this, using the factor 5.7. In all cases the figures given are the average of six determinations.

TABLE 10.—*Percentages of wet gluten, of dry gluten, and of actual protein obtained from 10 grams of flour.*

Temp. 25°	Patent unbleached			Patent bleached			Low grade		
	Wet	Dry	Protein	Wet	Dry	Protein	Wet	Dry	Protein
Distilled H_2O	30.4	9.6	8.49	28.0	8.4	7.62	45.5	14.8	12.13
0.5% NaCl	34.4	10.3	9.21	33.8	10.2	9.13	51.7	13.4	11.29
Tap water	33.4	10.7	9.47	33.6	10.5	9.35	46.8	14.6	12.12
Temp. 30°									
Distilled H_2O	.....	.....	.....	.....	.....	.....	42.8	14.4	11.82
0.5% NaCl	.....	.....	.....	.....	.....	.....	47.4	13.6	11.41
1% NaCl	.....	.....	.....	.....	.....	.....	47.0	13.3	11.16
2% NaCl	.....	.....	.....	.....	.....	.....	44.8	13.3	11.00
M/10 K_2HPO_4	.....	.....	.....	.....	.....	.....	27.9	8.6	7.23
M/20 K_2HPO_4	.....	.....	.....	.....	.....	.....	41.3	11.7	9.75
M/40 K_2HPO_4	.....	.....	.....	.....	.....	.....	43.3	12.7	10.69

When carbon-dioxide-free distilled water is used as the washing agent, bleached patent flour gives a lower per cent of wet gluten, dry gluten, and protein than does the same flour unbleached, whereas low-grade flour gives higher figures than either. The per cents of wet gluten, dry gluten, and protein, respectively, are practically the same in the case of the patent flours whether 0.4 per cent sodium chloride or tap water is used. Furthermore, the figures for the corresponding factors of the bleached and unbleached flour with the same solution agree very closely. With both the salt solution and the tap water, the figures for the three factors are higher than the corresponding figures obtained when distilled water was the washing agent. Quite a different result appears in the case of the low-grade flour. The figures for the three factors are very nearly the same with the tap water and the distilled water, whereas the salt solution gives a higher wet gluten but a lower dry gluten and protein figure than either of the other washing agents. All three

washing agents give higher figures for the three factors on the low-grade flour than for the corresponding factors on the other two flours.

When the washing agent is sodium chloride solution of higher concentration than 0.5 per cent, the wet gluten decreases slightly, whereas the dry gluten and protein remain practically the same. With all three concentrations of salt the two latter figures are practically the same as with distilled water, whereas in all cases the salt solution gives higher figures for wet gluten than does water. Dipotassium phosphate solution of concentration $M/10$ gives much lower figures for all three factors than does sodium chloride solution, tap water, or distilled water. As the concentration of the phosphate solution becomes less the figures for all three factors become larger but even with $M/40$ phosphate are not as great as the corresponding figures with any of the sodium chloride solutions.

In Table 11 are given the percentages of wet gluten, dry gluten, and protein for a patent flour and a low-grade flour when seven different concentrations of salt solution as well as distilled water were the washing agents. The percentages given are in all cases averages of three sets of figures. The flours were obtained from 1915 wheats, while those used in obtaining the results of Table 10 came from 1914 wheats.

From the unbleached flour a smaller per cent of wet gluten is obtained when water is the washing agent than when any of the salt solutions are the washing agents. With increasing concentrations of sodium chloride solution the percentage of wet gluten rises, reaching a maximum when 1.00 per cent salt solution is the washing agent. Very striking is the fact that the percentages of dry gluten and of protein are the same whether distilled water or one of the salt solutions is the washing agent. In other words, washing with any of the salt solutions brings about *swelling of the gluten due to water absorption.* A 0.5 per cent magnesium chloride solution gives similar results.

TABLE 11.—*Gluten washed from flour with different concentrations of NaCl solution.*

Solution temp. 22.5°	Unbleached patent			Low grade		
	Wet gluten	Dry gluten	Protein	Wet gluten	Dry gluten	Protein
CO_2 free water...	29.3	9.4	8.3	39.7	12.9	10.14
0.1% NaCl sol...	31.7	9.8	8.7	42.0	12.2	9.9
0.25% " "	31.8	9.6	8.6	45.2	11.9	9.6
0.50% " "	32.3	9.5	8.5	45.1	11.4	9.5
1.00% " "	32.5	9.5	8.3	44.0	11.4	9.4
1.50% " "	32.4	9.6	8.4	43.5	11.4	9.3
2.00% " "	32.2	9.7	8.3	42.0	11.6	9.4
2.50% " "	32.1	9.7	8.4	41.2	11.5	9.5
0.5% $MgCl_2$ sol..	34.6	9.4	8.4	....	....	....
CO_2 free water...	29.2	9.3	8.3	38.4	12.7	10.19

In the case of the low-grade flour the results are somewhat different. Distilled water gives the lowest per cent of wet gluten but the highest per cents of dry gluten and of protein of any of the washing agents used. But salt solutions cause a swelling of the gluten the same as with patent flour. The per cent of wet gluten rises with increasing concentration of salt solution and then falls just as with the patent flour. On the other hand, the per cents of dry gluten and of protein fall as we pass from water to salt solutions, reaching a minimum at about 0.5 per cent salt solution, and then remaining practically constant. In other words, here again washing with salt solutions causes swelling of the gluten. That the dry gluten and protein fall is probably due to the fact that higher concentrations of salt solution remove some of the salt soluble protein material of the flour.

In Table 12 are given the results obtained on washing several mill-stream flours with distilled water, with 0.5 per cent sodium chloride solution, and with tap water. These flours came from 1914 wheat and correspond to flours in Table 10. In the case of the first and third middlings, tap water and 0.5 per cent sodium chloride solution give practically the same results for wet gluten, dry gluten, and protein. Distilled water gives lower results than either. In the case of the fifth middlings the per cents of wet gluten are in the ascending order—distilled water, tap water, and 0.5 per cent sodium chloride solution. The dry gluten and protein figures are the same with all three washing agents; whereas in the case of the seventh middlings tap water gives practically the same wet gluten figures as does distilled

water. A 0.5 per cent salt solution gives a higher result than either. Again, the dry gluten and protein figures are practically the same with all three washing agents, but are higher than for the corresponding factors of the other three flours. In other words, the seventh middlings gives results similar to those obtained with the low-grade flour, as shown in Table 10, whereas the first, third, and fifth middlings give results similar to those obtained with the patent flour of Table 10. In Table 14 are given the percentages of protein in the original flours which were used in this study. Reference to this table shows that the first middlings of the 1914 flour has practically the same protein content as the patent flour of the 1915 series. Comparing the figures as given in Tables 11 and 12 it is seen that these two flours which are alike in protein content give quite *different* figures for wet and dry gluten and protein when distilled water is the washing agent, but practically the *same* figures with 0.5 per cent salt solution as the washing agent. Again, the third middlings and the patent flour of the 1914 series have practically the same nitrogen content. Reference to Tables 10 and 11 brings out the fact that these two flours also give quite *different* results when distilled water is the washing agent but very *similar* results when 0.5 per cent salt solution or tap water is the washing agent.

Finally, Table 13 shows that hydrochloric acid solutions in concentration of $N/2,000$ (0.0018 per cent) will not give a gluten ball.

TABLE 12.—*Mill-stream flours washed in water and 0.5 per cent NaCl solution.*

Flours Temp. 22.5°	Solution	Wet gluten	Dry gluten	Protein
		Per cent	*Per cent*	*Per cent*
1st Middlings....	CO_2 free water.......	23.5	7.1	6.4
	0.5% NaCl solution..	32.1	9.4	8.4
	Tap water...........	31.4	9.7	8.7
3rd Middlings...	CO_2 free water.......	27.8	8.7	7.8
	0.5% NaCl solution..	34.5	10.3	9.3
	Tap water...........	33.7	10.6	9.4
5th Middlings...	CO_2 free water.......	33.7	11.2	10.0
	0.5% NaCl solution..	37.5	11.2	10.0
	Tap water...........	35.7	11.5	10.2
7th Middlings...	CO_2 free water.......	36.0	12.4	10.7
	0.5% NaCl solution..	38.6	12.0	10.3
	Tap water...........	36.6	12.3	10.7

TABLE 13.—*Unbleached patent flour washed with different solutions.*

Temp. 22.5°	Wet gluten	Dry gluten	Protein
	Per cent	*Per cent*	*Per cent*
N/2000 (0.0018%) HCl solution	(Gluten was	too soft to	handle)
N/4000 (0.0009%) HCl solution	24.1	7.4	6.5
N/4000 (0.0009%) HCl + 0.5% NaCl	33.2	9.6	8.6
CO_2 free water	29.2	9.3	8.3

TABLE 14.—*Protein content of the flours used in the experimental work.*

Flours	1914	1915
	Per cent	*Per cent*
Patent unbleached	11.00	10.06
Patent bleached	10.88	....
Low grade	14.37	12.94
First middlings	10.04	....
Third middlings	10.96	....
Fifth middlings	11.97	....
Seventh middlings	12.88	....

The gluten is rendered so soft and sticky that it cannot be collected. A N/4000 (0.0009 per cent) acid gives smaller wet gluten, dry gluten, and protein figures than does water. When 0.5 per cent salt is added to N/4000 acid, figures very nearly the same as those with 0.5 per cent salt alone are obtained, as shown in Table 11. The salt overcomes the effect of the acid in causing disintegration of the gluten.

Our experiments suggest first of all that carbon-dioxide-free distilled water is the proper washing agent to be used in making gluten determinations by the ordinary method. Distilled water as the washing agent more often reveals differences in the quantity and character of wet gluten in different flours than does tap water or a salt solution. If any importance is to be attached to the amount and quality of the wet gluten, it is clear from the experiments here reported that concordant results cannot be obtained when different washing agents are used.

The authors propose the following as a satisfactory method for the determination of gluten. Weigh 10 grams of flour into a round-bottomed cup. Work into a stiff dough with freshly boiled distilled water and allow to stand under water for 1 hour. Then work in a stream of the distilled water for 14 minutes over a bolting-cloth frame, to catch any pieces which may fall. Then work in the fingers for 1 minute and weigh on a tared dish.

The weight of dry gluten may be obtained after drying at 110°C. to constant weight. As a check, nitrogen determinations may be made on the dry gluten.

The explanation for some of the facts brought out by our experiments is not at present evident. We have repeatedly demonstrated that gluten, prepared by washing the starch from flour with distilled water, does not change in weight when placed in salt solutions even when the concentration of the latter is as high as $N/2$ (2.9 per cent). On the other hand, larger amounts of wet gluten are obtained by washing the starch from flour with salt solutions of concentrations varying from 0.1 per cent to 2.5 per cent than are obtained when distilled water is the washing agent. Furthermore, our figures show this increased weight obtained with the salt solutions to be due to hydration of the gluten. In other words, when salt solutions are the washing agents gluten swells more (absorbs more water) than when distilled water is the washing agent. These facts are not in harmony with the results of our experiments on the swelling of gluten as reported in the first part of this paper. When pieces of gluten are simply placed in salt solutions, for several hours even, swelling is inhibited.

These facts do not in any way modify our conclusions in regard to the effect of acids and salts on the character of loaf obtained when the flour is made into bread. The different results are without doubt due to the difference in conditions in the two experiments. When moist gluten is allowed to remain in contact with a solution, conditions are not the same as they are when gluten is washed in a continuous stream of that solution. In the latter case, the gluten is washed in the fingers so that the solution permeates the whole mass; and since the solution is constantly changing, other substances besides starch are washed from the mass. The first condition is more nearly like the one which obtains in the bread-making process.

While no doubt the different results are due to the difference in conditions, still the complete explanation is not apparent. It is possible that washing with salt solution changes the degree of dispersion of the gluten in such a manner as to favor increased water absorption. The facts present a problem in colloidal chemistry which requires further study. The authors plan in the near future an extended research in this field.

SUMMARY.

1. It is shown that wheat gluten is an emulsoid colloid and shows all the properties of this class of compounds.

2. Gluten absorbs water from dilute acid solutions, thereby losing its tenacity and ductility, becoming soft and gelatinous. The presence of small amounts of neutral salts in the dilute acid solutions inhibits water absorption by gluten.

3. It is pointed out that the bread-making qualities of dough made from wheat flour are dependent on the quantity and quality of the contained gluten. Quality of gluten is regulated by the kind and concentration of the acids and salts present in the dough. If the kind and amounts of the acids and salts are such as to favor water absorption, the quality of the gluten will be poor, whereas the presence of acids and salts in such amounts as tend to inhibit water absorption makes for an improved gluten.

4. Results of experiments are presented which show that carbon-dioxide-free water is the ideal washing agent to be used in making gluten determinations. A standard method for gluten determinations is proposed.

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(5-26-'16—5 M.)

RESEARCH BULLETIN NO. 9

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

A PHYSIOLOGICAL STUDY OF TWO STRAINS OF FUSARIUM IN THEIR CAUSAL RELATION TO TUBER ROT AND WILT OF POTATO

By GEO. K. LINK

ACCEPTED FOR PUBLICATION MARCH 10, 1916

DISTRIBUTED SEPTEMBER 15, 1916

SECOND EDITION DISTRIBUTED JUNE 30, 1917

[Reprinted from Botanical Gazette, Vol. LXII, Pages 169–209]

LINCOLN, NEBRASKA
U. S. A.

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A PHYSIOLOGICAL STUDY OF TWO STRAINS OF FUSARIUM IN THEIR CAUSAL RELATION TO TUBER ROT AND WILT OF POTATO

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GEORGE K. K. LINK

(WITH THIRTEEN FIGURES)

There is little doubt among phytopathologists that members of the genus *Fusarium* play an important role in producing diseased conditions in many plants, both wild and cultivated. According to WOLLENWEBER (**41**), *Fusarium* spp. produce wilt in members of the following families: Liliaseae, Bromeliaceae, Musaceae, Solanaceae, Convolvulaceae, Leguminosae, Malvaceae, Linaceae, Cucurbitaceae, Cruciferae, Compositae, Araliaceae, Caryophyllaceae, and Pedaliaceae.

History

The genus *Fusarium* was established by LINK (**20, 21**) in 1809, and *Fusarium* species were reported on rotted and ring-discolored tubers by MARTIUS in 1842, HARTIG in 1846, and SCHACHT in 1856. PIZZIGONI (**29**) and WEHMER (**38, 39**) demonstrated by experimental inoculation that *Fusarium* species can bring about tuber rot. They referred to the *Fusarium* in question as *F. solani*. Others, however, among them FRANK (**11, 12**), repeating their work, obtained negative results so far as *Fusarium* species were concerned; while DE BARY (**6**) and many others regarded the *Fusarium* spp. as nothing more than obligate saprophytes.

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The credit of first demonstrating experimentally the relation of *Fusarium* spp. to certain plant wilts belongs to SMITH (**34**), who found a *Fusarium* responsible for watermelon wilt. SMITH and SWINGLE (**35**) reported a potato wilt and tuber rot which they considered due to a *Fusarium* which they called *F. oxysporum*. They considered this organism identical with *F. solani* of PIZZIGONI and WEHMER, and used the oldest name available, *F. oxysporum* (SCHLECHTENDAHL, 1824); however, they reported no experimental inoculations. PETHYBRIDGE and BOWERS (**28**) reported a dry rot due to *F. solani*, and LONGMAN (**22**) also reported a dry rot due to a *Fusarium*.

Many pathologists and mycologists entertained considerable doubt as to the parasitic nature of *Fusarium* spp., while others were quite convinced of their parasitic nature. SORAUER (**36**) was quite positive in his decision, while MASSEE (**25**) wavered. LINDAU (**18**) remained skeptical and referred to the *F. oxysporum* of SMITH and SWINGLE as a "Mischart." DUGGAR (**10**) was quite positive in his decision. Much of this difference of opinion undoubtedly was due to the confusion that prevailed as to the status of *F. solani, F. oxysporum*, and the genus in general, since no basis for extended morphological study of the genus had been established, and even the genus itself had not been sharply defined. MASSEE (**25**) considered *F. solani* to be the conidial form of *Nectria solani;* while REINKE and BERTHOLDT (**30**) considered it the conidial form of *Hypomyces solani.* LOUNSBURY (**23**) tried to arbitrate the matter by suggesting that *F. solani* and *F. oxysporum* are one and the conidial stage of *Nectria solani.* APPEL and WOLLENWEBER (**5**) published a monograph in which they defined the genus and brought some order into the chaos of species. Among other radical changes they dropped *F. oxysporum* and established *F. orthoceras* in its place.

MANNS (**24**) demonstrated by experimental inoculation that a *Fusarium*, which he designated (following SMITH and SWINGLE) as *F. oxysporum*, could produce tuber rot and wilt. He made no morphological studies, however, and undoubtedly had not had access to APPEL and WOLLENWEBER's monograph.

JAMIESON and WOLLENWEBER (**16**) published an account of a dry rot of tubers induced by a *Fusarium* which they described as a

new species (*F. trichothecioides* Wr.). They refer to it as "a wound parasite capable of destroying potato tubers" and say "this disease is clearly differentiated from the wilt and dry rot ascribed by SMITH and SWINGLE to *F. oxysporum*."

Later, the writer (**19**) submitted his studies of a dry rot occurring among Nebraska potatoes as a thesis to the Graduate Faculty of the University of Nebraska. The work was done at the request of Dr. E. MEAD WILCOX, and consisted in part of a study of the morphology of a *Fusarium* that had been isolated from dry rotted tubers in 1908 by Miss VENUS W. POOL from potatoes that farmers had sent in from throughout the state during the season 1907-1908. Miss POOL established the causal relation of this *Fusarium* to the dry rot by experimental infection, and named the organism in manuscript *F. pulverulentum,* because of its powdery habit of growth. Both field and laboratory work were carried on for several years, and it was found that this organism caused primarily a dry rot of the tuber, and that it was not the *F. oxysporum* of SMITH and SWINGLE, a culture of *F. oxysporum* having been furnished the laboratory for comparative work through the courtesy of Dr. SMITH. The results were to have been published in 1911, and the organism was to be named *F. pulverulentum*, but upon the appearance of APPEL and WOLLENWEBER'S monograph Dr. WILCOX proposed to the writer that he reinvestigate the organism along the lines suggested by these authors. This was especially desirable since *F. oxysporum* had been dropped and several new species established. Not only was this carried out, but the whole etiology was gone over again and all of Miss POOL'S results verified. It was found that APPEL and WOLLENWEBER (**5**) had not described the species, and consequently it was described as *F. tuberivorum* WILCOX and LINK (**40**). It was so named because of the apparent restriction of its activity to tubers.

A comparison of this paper and the paper of JAMIESON and WOLLENWEBER (**16**) made it seem quite likely that both were dealing with the same organism. The organism was isolated in the Washington laboratories from potatoes sent in from Washington, Nebraska, and other states in 1910, and WOLLENWEBER upon his arrival in the laboratory, using his monograph as the basis, described

it as a new species. He told the writer in 1913 that he felt convinced that we had described one and the same thing. Comparative studies made by the writer during the past year verify this point of view, and since the Nebraska publication by WILCOX, LINK, and POOL (**40**) did not appear in print until 1913, the name *F. trichothecioides* should be adopted.

WOLLENWEBER (**41, 42**) published a further paper in which he categorized the *Fusarium* spp. very sharply, dividing the genus into sections on the basis of physiological (that is, pathogenicity) and morphological (that is, conidia and chlamydospores) characters. *F. oxysporum* was again established and taken as the representative of the section ELEGANS, which comprises vascular parasites; and *F. trichothecioides* was put into the section DISCOLOR, which comprises parenchyma destroyers. He distinguished sharply between these and also between the vascular ring-discoloring *Fusarium* species of section ELEGANS and the tuber-rotting *Fusarium* species of sections DISCOLOR, GIBBOSUM, MARTIELLA, etc.

Referring to the papers by SMITH and SWINGLE (**35**), MANNS (**24**), and others, particularly to that by MANNS, he writes: "They do not separate fusarioses causing tuber rot from those causing both the wilt diseases of the plant and ring discoloration of the tuber, so that the reader might conclude that both wilt disease and tuber rot are caused by the same organism." Referring to his own experiments, he writes: "It also brings out the striking fact that the fungus, a typical xylem inhabitant, does not entirely destroy the tuber without the help of tuber rot *Fusarium* or bacteria," and "the fact that *F. oxysporum* causes the wilt of growing potato plants and only uses the xylem of the stem end of tubers for over-wintering, without producing a rot of the parenchyma, leads to interesting comparisons with the following 4 species which are able to destroy the tuber entirely from artificial wounds, namely, *F. coeruleum* (Lib.), *F. trichothecioides* Wr.," etc., and finally "the fact that the latter (*F. oxysporum*) cannot produce a tuber rot gives a biological contrast to the wound parasites of the tuber, and the fact that they cause the wilt disease of the growing plant presents a contrast to the saprophytes."

Problem and method of attack

In the spring and summer of 1914 the writer discussed the *Fusarium* situation as outlined by WOLLENWEBER with Dr. E. M. WILCOX and Dr. WILLIAM CROCKER. The former suggested that the whole situation ought to be gone over, and the latter that it would be of interest to search for the physiological basis of this alleged biological contrast. It is clear that, if the strict categories of WOLLENWEBER exist, then potato parenchyma must possess either an absolute or an effective immunity toward *Fusarium* spp. of the ELEGANS section, and that *Fusarium* spp. of the DISCOLOR section are either absolutely or practically unable to produce vascular mycoses or wilts.

The purpose of this research was twofold: (1) to determine whether such a sharp biological contrast exists; and (2) to determine what is the physiological basis for such a contrast. Experimental infections of potato plants and tubers were used for the first phase of the problem. It was clear that the second phase might involve a great many considerations, such as the structural, compositional, and metabolic nature of both host and parasite, as well as the relation of environmental factors to these. The important role played by the structural and compositional peculiarities of the potato and the influence of external factors upon these is well illustrated by the studies of APPEL and KREITZ (**1, 3**) on the efficacy of the cork layer in checking bacterial invasions of the tuber. Considerations of time and equipment limitations made it obligatory that the scope of the work be limited to a study of a few representative strains of the groups.

The writer is under obligation to the Departments of Agricultural Chemistry, Horticulture, and Experimental Agronomy of the University of Nebraska Experiment Station for the use of materials and equipment; to Miss ETHEL BEATY for help in much of the laborious routine: to Dr. FLORENCE A. McCORMICK for valuable help in the anatomical and microtechnical phases of the problem; and to Mr. R. A. DAWSON for help in preparing the photographs.

The writer decided to work with *F. oxysporum* as representative of the vascular parasite section (ELEGANS), and with

F. trichothecioides or *F. tuberivorum* as representative of the parenchyma-invading section (DISCOLOR). Since it was desirable that the identity of the organisms be well established, the writer asked Mr. W. A. ORTON, in whose laboratories Dr. WOLLENWEBER had carried out his recent work, for cultures of the organisms. It was impossible to get cultures which had been authenticated by Dr. WOLLENWEBER, since he had gone to war, but through the courtesy of Mr. ORTON, Mr. CARPENTER (Dr. WOLLENWEBER'S assistant) furnished a strain of *F. trichothecioides* (no. 41, 1916) and a strain of *F. oxysporum* (no. 3345A). The other strains of *F. trichothecioides* used had been isolated by the writer in 1911, and were described as *F. tuberivorum*. Several strains of *F. oxysporum* isolated from Nebraska potatoes were also used.

Pure cultures of these organisms were maintained on sterilized rice in plugged Erlenmeyer flasks, and these were used as a point of departure for all the work recorded.

I. Infection experiments

(1) EXPERIMENTAL INFECTION OF TUBERS

Tubers of the Early Ohio and Red Cobbler varieties were used in these experiments. Only sound tubers were selected, and these were thoroughly cleansed and sterilized before infection. At first they were sterilized by the formaldehyde gas method recommended by WOLLENWEBER (**41**). Several difficulties were encountered in using this method. It was found very difficult to remove the last traces of the gas without contaminating the chamber, and the tubers often showed the characteristic formaldehyde vapor injuries that have been discussed in bulletins of the New York Experiment Station (**13**, **37**). Consequently, the writer abandoned the first method and sterilized tubers by immersing in 1:1000 $HgCl_2$ solution for 1.5 hours. Inoculation was carried out by removing a piece of the cortex with a sterile cork borer, placing an infected grain of rice into the hole, and then replacing the piece of tuber tissue. The wound was then sealed with sterile grafting wax and the tuber placed into sterile chambers. This proved an efficient and convenient way of carrying out the great number of experimental inoculations made.

The first inoculations were made in December 1914. The cut ends of 20 Early Ohio tubers were wetted with spore suspensions of *F. trichothecioides* and 5 tubers were kept as controls. Four inoculated and one control potato were kept in each compartment at a temperature of 25° C. in an almost saturated atmosphere. After 4 weeks all of the inoculated tubers were in advanced stages of rot.

On January 31, 3 potatoes were inoculated according to the second method with *F. oxysporum*, and 3 with *F. trichothecioides*, and kept at 20° C. until February 17. Two of the former set were slightly rotted and one totally, while the entire latter set was rotted severely. The controls showed no rot (fig. 1).

On January 15 another series was started which was kept at a temperature ranging from 15-20° C. until February 15. Six sets of 3 tubers each were started and each set was kept in a separate sterile chamber, 2 tubers of each set being inoculated by smearing cut surfaces with agar grown inoculum. Sets I, II, and III were inoculated with *F. oxysporum*, and sets IV, V, and VI with *F. trichothecioides*. In set I, one inoculated tuber was rotted, while the other and the control were sound; in set II, one was deeply rotted and the others sound; in set III, one was deeply rotted and the others sound; in set IV, two were rotted and the control sound; in set V, two tubers were rotted slightly and the control sound; and in set VI, two tubers were rotted and the control sound.

F. oxysporum and *F. trichothecioides* were re-isolated from these rotted tubers by placing tissue cut from such tubers on plated glucose agar. Nothing other than the organism with which the tuber had been inoculated developed. Inoculum from these plates was used in infecting tubers again with the same results.

Since these results were at variance with the statements of Wollenweber the experiments were repeated with hundreds of tubers, and the results were verified.

Discussion.—Tubers inoculated with *F. oxysporum* did not develop the ring discoloration that is considered characteristic of the activity of *F. oxysporum*, but a general rot of the whole tuber. Generally, however, this was not a dry rot, but a rot that resembles more the soft rots of bacterial origin, although it is not accompanied

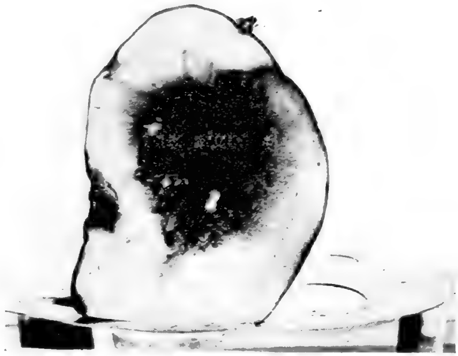
by the offensive odors of bacterial rots, producing a blackening and softening of tissues which extends a considerable distance beyond the actual site of the organism. This was demonstrated microscopically and culturally. At times, however, especially in cold, dry conditions, a dry rot as typical as that produced by *F. trichothecioides* was produced. *F. trichothecioides* invariably produced a dry rot with only a very limited darkened zone extending beyond the destroyed zone, made up of large cavities and a mixture of disintegrated, dry, shrivelled tissue and fungus tissue. No darkening extended beyond the actual site of the fungus and no softening of tissue occurred. Microscopic examination revealed the fact that *F. trichothecioides* attacked the tissue intracellularly and destroyed each cell completely before it proceeded to the neighboring cell, while *F. oxysporum* attacked the tissue intercellularly at first, and then attacked the cells intracellularly, but not until the tissue had been blackened and disorganized. In this way a softened tissue without cavities was produced. These rots produced experimentally with pure cultures of *F. oxysporum* lend support to the observations and conclusions of SMITH and SWINGLE (**35**), MANNS (**24**), who report the occasional appearance of black specks in the parenchyma of tubers infected with *F. oxysporum*, and JONES (**17**), who attributes stem end rot of tubers to the activity of this organism, although they may have dealt with "Mischarten." SHERBAKOFF (**33**) reports certain strains of species of ELEGANS (using the section as a morphological group) to be tuber rotters. He distinguishes between *Fusarium* spp. that are tuber rotters and such as are vascular element inhabitants.[1]

(2) EXPERIMENTAL INFECTION OF LIVING PLANTS

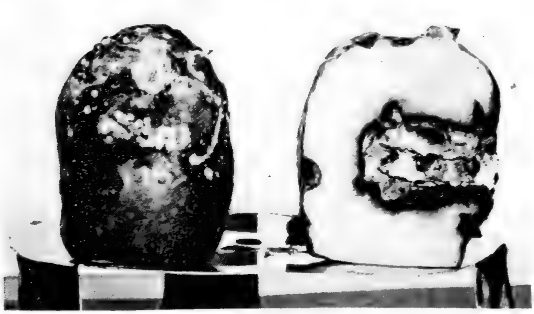
A series of experimental inoculations of healthy potato plants with *F. oxysporum* and *F. trichothecioides* were carried out, in an attempt to determine whether or not *F. trichothecioides* is unable to

[1]After these experiments had been concluded and this paper written, a paper by CARPENTER (**7**) has appeared. This represents a wholly independent although simultaneously conducted piece of work. The results of CARPENTER make it quite probable that the observations made by the writer on a few strains of *F. oxysporum* are of quite general application, since he arrives at the same conclusions for numerous though different strains of *F. oxysporum*. His conclusions as to the method of attack by the fungus and the nature of the rot are practically identical with the writer's.

produce wilt, or whether the potato plant enjoys an effective or practical immunity rather than an absolute one. Even though WOLLENWEBER (**41**) did not consider *F. trichothecioides* a wilt



A



B *C*

FIG. 1.—Tuber rot produced in laboratory with *Fusarium oxysporum*, and *F. trichothecioides*; *A*, soft rot produced by *F. oxysporum*, incubated at 20° C. for 17 days, Early Ohio variety; *B*, exterior of tuber rotted by *F. trichothecioides*, incubated at 20° C. for 17 days, Early Ohio variety; *C*, dry rot produced by *F. trichothecioides*, incubated at 20° C. for 17 days, Early Ohio variety.

producer in his 1913 paper, there is a reference in the 1912 paper by Jamieson and Wollenweber (**16**) to a wilt produced by *F. trichothecioides.* They referred to inoculation experiments, and report wilting in 12 days, "accompanied by a yellowing of the leaves and a discoloration of the tissues." The results of all of the writer's attempts of 1911-1912 to produce wilting of potato plants with *F. trichothecioides,* excepting one, were negative. During the past winter, however, it was noticed again and again that sprouts of tubers experimentally infected with this organism were dying. Microscopic and cultural studies left no doubt that this organism was responsible for the death of the sprouts.

Encouraged by these observations, the writer carried out some preliminary experiments on potato plants. Quartz was sterilized in 6 inch flower pots in the autoclave, and 8 plants that were about 10 cm. high were transplanted into these, the stems of some being smeared with rice infected with *F. trichothecioides,* and those of others with rice infected with *F. oxysporum.* The plants so inoculated and the controls were kept under bell jars. In three days the three plants smeared with *F. oxysporum* and two smeared with *F. trichothecioides* were dead, while the third one of the latter set and the controls remained healthy. The experiment was also conducted with potato plants growing in the open bench in the greenhouse, with similar results. The soil in this case was not sterilized.

The potato plants used in the following experiments were grown from sterilized tubers of the Early Ohio and Red Cobbler varieties in soil in 6 inch pots which had been thoroughly sterilized by heating in an autoclave for 4 hours on two consecutive days at 15 lb. pressure. The soil was watered with sterile water throughout the experiments.

On February 15, fifteen pots were planted with Early Ohio tubers and the soil of one set of 5 was infected with rice infected with *F. oxysporum,* of another with rice infected with *F. trichothecioides,* while the third set was left as a control. The controls came up in due time, while not a single one of the others came up. This experiment was repeated several times, but in no case was so striking a result obtained, although it often happened that some sprouts showed lesions, that some failed to come up, and that some were

tardy in coming up. *Fusarium* spp. were isolated from such lesions. These lesions are identical in appearance with lesions found on potato stems and roots in the field which often are designated as "foot disease" and ascribed to the activity of *Rhizoctonia*. Late in May other series were started and the soil was infected with rice and spore suspensions. No infections resulted at all, even though the inoculum was derived from the same source as that used in earlier experiments.

On March 12, sprouts that were just breaking through the ground were uncovered and smeared with rice infected either with *F. oxysporum* or with *F. trichothecioides*, 6 sprouts being used in each set. The plants were wounded no more than was inevitable in removing the soil. The soil was then replaced. The soil in the controls was removed in the same way, but no inoculum was applied. The 12 sprouts to which inoculum had been applied were killed, while the controls remained healthy. There was no spreading of the disease to other sprouts, even where an abundance of inoculum was applied.

The affected sprouts reminded one forcibly of affected sprouts in potato fields in the spring. Here and there in the fields one finds sprouts that look sickly and small, which usually wilt and die or remain sickly and small. Upon examination of such sprouts, prominent brownish, watery lesions are found. At times such sprouts overcome the trouble and make a fair growth, at least until transpiration becomes excessive. These lesions also account for many of the "poor stands" or failures of potatoes to come up evenly. If one digs in where a sprout ought to have come up, one can often find a tuber that has sprouted, but whose sprouts have been cut off entirely by such lesions. Often lateral buds develop into branches on such decapitated sprouts, only to be cut off again. If such a tuber finally manages to get a shoot above the ground, the shoot is sickly and backward. In 1912, 1913, and 1914 the writer plated the inner tissue of many such sprouts and almost invariably obtained cultures of various *Fusarium* spp., although often associated with *Rhizoctonia* and bacteria. Infection experiments conducted with *Rhizoctonia* in 1912-1913 gave almost uniformly negative results. The writer was at first inclined to refer

the major part of the potato troubles to the activity of this organism. Even though it is not the sole or even the main cause of Nebraska potato troubles it may play an important role. The work of APPEL (**2**), CORSAULT (**8**), DRAYTON (**9**), and MORSE and SCHAPOVALOV (**26**) gave results similar to those obtained by ROLFS (**31, 32**).

FIG. 2.—Wilt produced in laboratory with *Fusarium trichothecioides,* and control plant; *A,* control, Early Ohio variety; *B,* wilting and drying of leaves, 4 days after inoculation, Early Ohio variety.

On March 13, 24 plants grown in sterile soil were used in another experiment. These plants were about 10 cm. high at the time. The soil was removed from one shoot in each pot and the pots were arranged in 6 series. In series *A* the shoots were wounded and the wound smeared with *F. oxysporum* infected rice; in series *B* the sound stem was smeared with *F. oxysporum* infected rice; in series *C* the wounded shoots were smeared with *F. trichothecioides* infected rice; in series *D* the sound stems were smeared with *F. trichothecioides* infected rice; in series *E* no inoculum was applied to the wounded shoots; in series *F* the soil was merely removed and replaced (figs. 2 and 3).

On March 15 the following notes were taken. Series *A*: plant 1, slight curling of leaves; 2, apparently sound; 3, curling of leaves; 4, curling of leaves. Series *B*: plant 1, drooping leaves; 2, lower leaves drooping, upper leaves drying; 3, apparently sound; 4, apparently sound. Series *C*: plant 1, apparently sound; 2, some wilting; 3, some wilting; 4, some wilting. Series *D*: plants 1, 2, and 3, apparently sound; 4, wilting. By March 21 the plants

A *B*

FIG. 3.—Wilt produced in laboratory with *Fusarium oxysporum*, and control plant; *A*, control, Early Ohio variety; *B*, wilting of lower leaves and curling of upper leaves, 4 days after inoculation, Early Ohio variety.

infected with *F. oxysporum* showed a pronounced folding upward of leaves on the midrib, wilting and rolling on the margins of the leaves, the folding being most pronounced in the tips of the plants. The plants affected least showed discoloration on the margins, which at times was of a yellowish tint, at times purplish to violet. The leaves of plants most severely affected showed a yellowing and burning of the leaf margins. One plant, inoculated with *F. oxysporum*, developed a pronounced rosette, but overcame this later, growing into quite a normal plant (figs. 4 and 5). These symptoms remind one forcibly of certain symptoms of the leaf-roll disease which has received so much attention, and which has been made the

subject of thorough study by APPEL and his coworkers (**2**, **4**). Eventually the plants infected with *F. trichothecioides* showed much severer symptoms than those inoculated with *F. oxysporum* (fig. 6). Eight plants died in the former sets, and 3 in the latter. Plants infected with *F. trichothecioides* showed such severe and rapid burning

FIG. 4.—Leaf roll and rosette of field plant of the Pearl variety; August 1912, at the U. S. Substation at Mitchell, Neb.

and drying up of leaves that the typical wilting phenomena were scarcely realized. The vascular bundles were blackened and the blackening extended even into the petiole and the leaf veins. This rapid killing was at first strictly localized on that side of the plant to which the inoculum had been applied, even in the leaf, where the leaflets on one side of the midrib would be affected, and those on the other side not. Eventually in those cases in which killing of

the whole plant took place, the fungus girdled the whole stem, while plants that were not girdled lived on, even though one side was entirely destroyed. There was little lateral and subsequent vertical spreading of the fungus from one vascular strand to the other. These experiments were repeated with 25 other plants and in most cases the same symptoms were observed. These symptoms have been repeatedly observed in the dry land areas of Nebraska,

A *B*

Fig. 5.—Rosette produced in laboratory with *Fusarium oxysporum*, and control plant; *A*, control, Early Ohio variety; *B*, rosetted plant, 10 days after inoculation, Early Ohio variety.

but have always been looked upon as cases of "sun scald," and in previous experiments with wilting due to *F. trichothecioides* such cases were ignored.

Plants grown in soil infected with *F. oxysporum* and *F. trichothecioides* showed severe lesions of roots and stolons. Examination of roots affected with either organism showed that the cortical regions are first and most severely attacked, not only intercellularly, but also intracellularly, the cells being packed full with hyphae. In most cases the cortex could be sloughed off with exceeding ease. From the cortex the organisms invaded the stelar regions, where

F. oxysporum makes greater headway than the other and there causes a vascular mycosis more frequently, which accounts for its designation as a vascular parasite (figs. 7 and 8).

DISCUSSION.—If plants, experimentally inoculated, showed only light symptoms to begin with, most of them continued their growth with symptoms less severe than those shown in the field. If they showed severe symptoms early, these proved more severe and

A *B*

FIG. 6.—Wilt and death of potato plants produced in laboratory with *Fusarium trichothecioides*, 12 days after inoculation; Early Ohio variety; wilting is restricted to the side to which inoculum was applied.

more rapidly fatal than those in the field. The organisms in the field work much more insidiously, attacking the roots of the plant slowly but progressively, and permitting the plant, except in extreme cases, to readjust for its water requirements. These readjustments manifest themselves in the curling and rolling phenomena (figs. 4 and 9).

Potato plants in the irrigated sections show this phenomenon nicely. As long as cultivation and irrigation are maintained, the plant develops new roots progressively higher up, and the infected

plants get along fairly well, showing slight curling and wilting, although tuber development occurs. When in midsummer

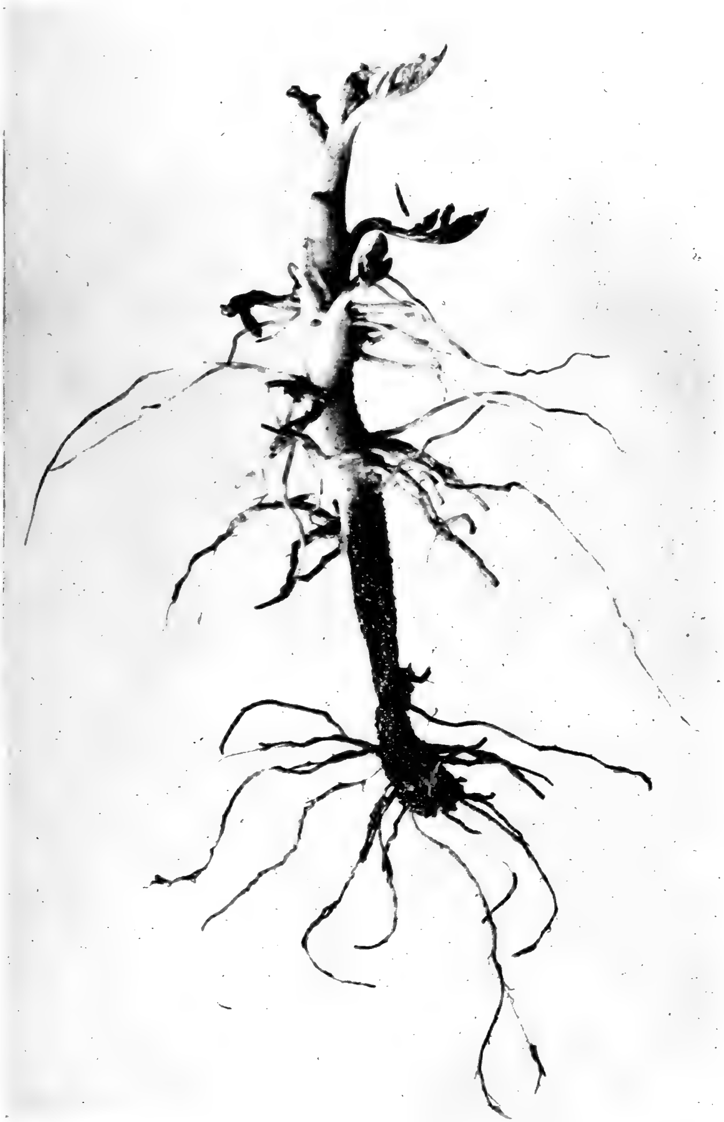


FIG. 7.—Lesions on stems and roots produced in laboratory with *Fusarium oxysporum*, 2 weeks after inoculation; Early Ohio variety.

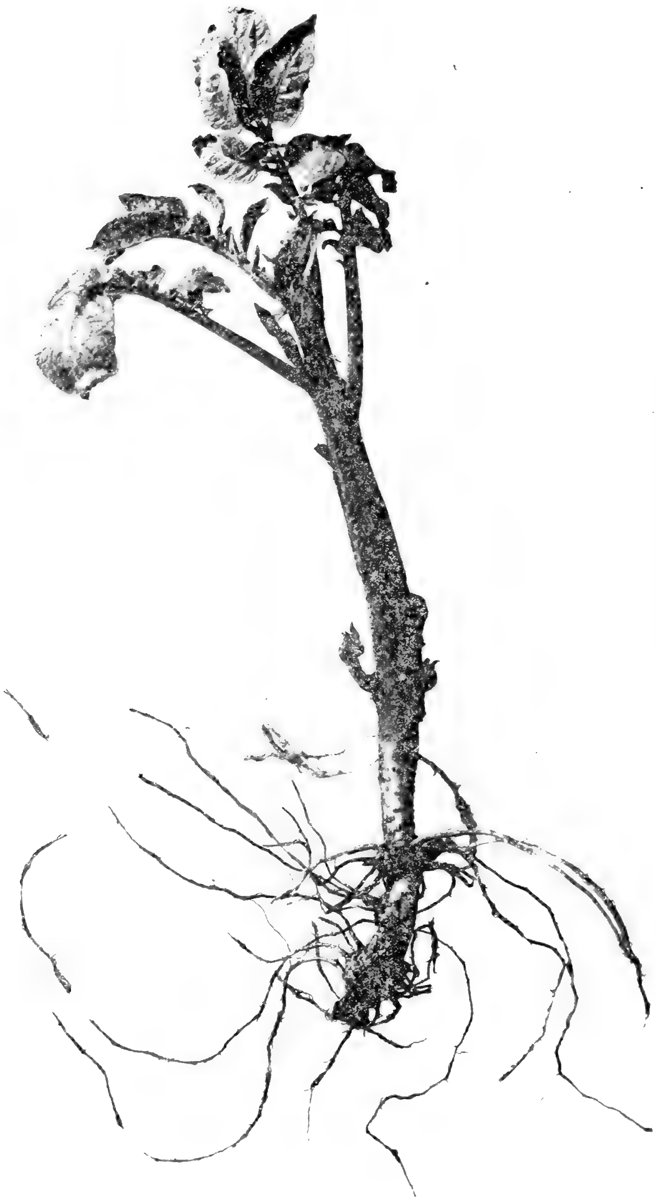


FIG. 8.—Root lesions produced in laboratory with *Fusarium trichothecioides*, curling and rolling of leaves, 2 weeks after inoculation; Early Ohio variety.

irrigation ceases and no more soil is heaped about the crown of the plant and transpiration requirements must be met by badly infected

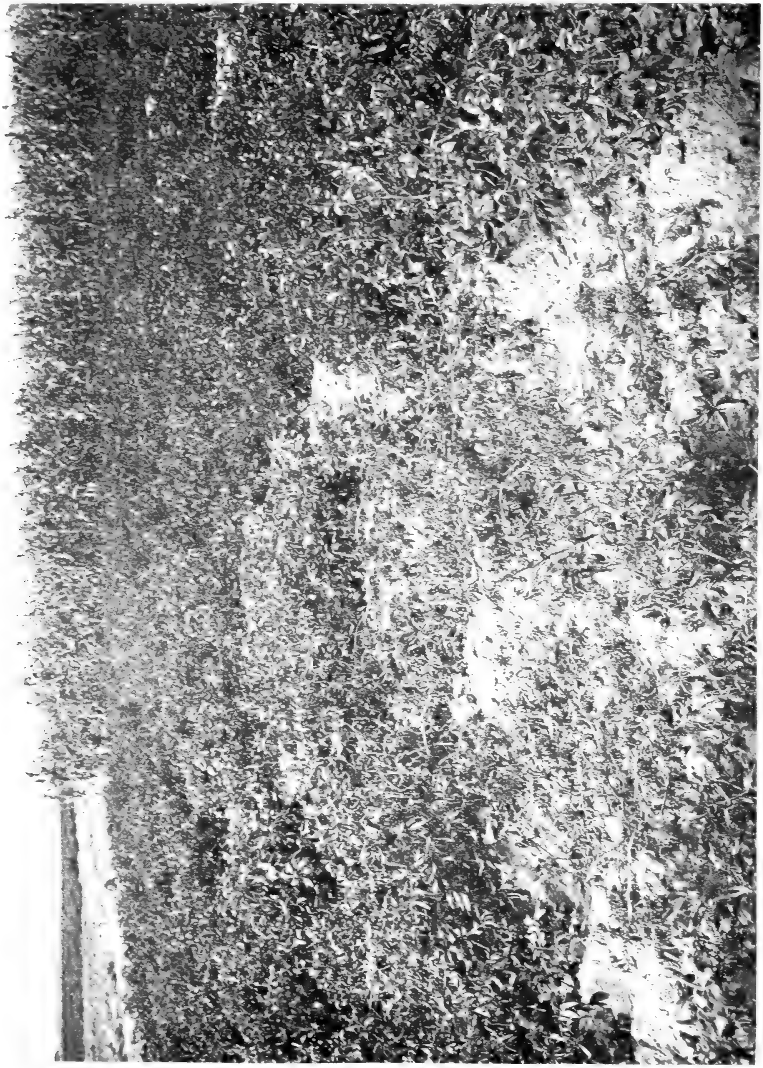


Fig. 9. Potato wilt and little potatoes in a field of the Pearl variety, August 1912, at Mitchell, Neb.

lower roots and a few healthy upper ones without the possibility of developing new roots, the plant soon succumbs. In this way we

get the exceedingly frequent phenomenon of large plants, usually with many small tubers, wilting down suddenly after the last irrigation. The frequent occurrence of aerial tubers, the prevalence of excessive numbers of small tubers, and the occurrence of few abnormally large tubers on such plants is also attributable to the insidious manner of attack. The organisms attack the stolons and main stem as well as the roots. Stolons with tubers in all stages of maturity can be found partially or completely cut off by lesions. As the balance between the photosynthetic and storage centers in such plants is disturbed, new stolons are developed nearer and nearer the surface and the stolons that are not attacked develop abnormally large tubers. Often the plant responds to this disturbance in the assimilation-storage balance by producing swellings of the aerial parts of the plant, the so-called aerial tubers. Many large plants can be pulled up with ease, because lesions make separation of the tops from the roots or even the basal portion of the stem easy. Such plants may show a comparatively sound main axis (fig. 10).

Infection carried over by the mother tuber, which is frequent, rarely permits the growth of stems more than 20 cm. high, and seldom allows the development of tubers. An early attack from without upon the main stem leads to equally disastrous results.

The wilts of the potato plant induced by *Fusarium* spp. have generally been considered vascular mycoses due to a clogging of the vascular elements. In fact, however, the symptoms are due to killing of the root system as much as to clogging of the vascular elements. It is true that members of the ELEGANS section, such as *F. oxysporum*, frequent the vascular elements, spreading in these rather than clogging them, but it is true also that they destroy roots in numbers. Again, even though some have referred to this disease as a root disease (SMITH and SWINGLE **35**), it is stated that the fungus enters a root, then spreads to the stelar part, and from there enters other roots and stolons. Just as much damage is done by the persistent attack from without upon roots and stolons, as noted by MANNS (**24**).

In the course of these experiments several questions were raised. The soil in these experiments surely was more severely

FIG. 10. A plant of the field shown in fig. 9; after showing slight curling and discoloration of leaves and formation of aerial tubers in earlier part of summer this plant suddenly wilted down and died; such a plant as this usually bears a great number of small and a few abnormally large tubers which are infected in the stem end with the fungus that killed the mother plant.

infected with the organisms than soil under field conditions can be, yet there were many plants grown in such soil that showed no infection whatsoever. Less success in producing wilt was observed as the season progressed. It remains a question whether this is due to a loss in vitality of the organism or to a gain in resistance in the plants, due to a change in the soil, tubers, or the organism.

Whether the success in producing wilt with *F. trichothecioides* and the apparent waning of this power is due to a gain or regain of virulency and a subsequent loss again is also an unanswered question. SHERBAKOFF (**33**), working with *Fusarium* spp., got uniformly negative results so far as producing wilt is concerned, and concluded that the results were due to a loss of virulency of the cultures or to some other important factor that had escaped attention.

Summary

It is quite apparent that some of the strains of *F. oxysporum* can cause tuber rot; that they can destroy tubers entirely without the aid of other *Fusarium* spp. or bacteria; that at least one *Fusarium* of the DISCOLOR section (*F. trichothecioides*) can produce wilt of stem; and that the biological contrast drawn by WOLLENWEBER between the *Fusarium* spp. is not as sharp as one would infer from his paper. It is possible that these strains of *Fusarium* spp. are morphologically identical with those described by WOLLENWEBER, but physiologically unlike them. That this rule, if it exists, is not so rigid generally, however, is noted by SHERBAKOFF (**33**), who found that no correlation exists between morphological relationship and pathogenicity.

Although *F. oxysporum* is not absolutely unable to attack potato parenchyma, the potato tuber, in which usually only the xylem elements are invaded, enjoys an effective immunity from its attacks; and although *F. trichothecioides* can attack any subterranean part of the living potato plant, generally all parts excepting the mature tuber enjoy an effective immunity from its attacks.

The data given in the second part of this paper may furnish a partial explanation of these phenomena.

II. Ecology and physiology of the organisms

METHOD AND DATA

1. TEMPERATURE RELATIONS.—Observations of cultures grown at ordinary temperatures showed that there is a striking difference in the rate of growth of the two organisms. Potato cylinder, rice, liquid potato, and glucose media, and glucose and potato agar cultures all showed that *F. oxysporum* makes a considerably greater initial growth at temperatures above 20° C. than does *F. trichothecioides.* At temperatures in the vicinity of 10-15° C., however, *F. trichothecioides* makes the greater initial growth, although these temperatures lie below its optimum. The same difference was noted in cultures on neutral and acid potato agar. This point was also tested with cultures on sterile slabs of potato tubers kept in Petri dishes. At 25° C., *F. oxysporum* covered such slabs completely when *F. trichothecioides* barely had made a start, while at 12° C. the situation was reversed.

When 1 per cent liquid glucose media were inoculated with spore suspensions of *F. oxysporum,* visible growth was made in 16 hours; when *F. trichothecioides* was used, 30–42 hours elapsed before visible growth was made. This holds for temperature above 20° C. The optimum temperature for *F. oxysporum* was about 30° C., and for *F. trichothecioides* about 20-22° C., both varying slightly with the medium used. The maximum for *F. oxysporum* lay between 38 and 40° C. The optima and maxima were higher for cultures in potato extract than for glucose media cultures. The writer has not been able to determine the minima accurately because of inadequate apparatus. HUMPHREY (**15**) gives 4° C. as the minimum growth temperature for a certain strain of *F. oxysporum.*

Potato agar cultures of *F. oxysporum* and *F. trichothecioides* could endure a temperature of 40° C. for 5 and for 20 hours respectively and remain viable. Exposure to 50° C. for 5 hours killed *F. trichothecioides,* but not *F. oxysporum;* while exposure for 20 hours killed both. Some *F. oxysporum* cultures survived 5 hours exposure at 57° C.

The growth relations were also checked up quantitatively. In these experiments, as well as in all the following ones, the method

suggested by HASSELBRING (**14**) was followed. Erlenmeyer flasks of 200 cc. capacity were used with 50 cc. of solution per flask. The solutions in the flasks were autoclaved for 10 minutes at 7 lb. pressure, and then inoculated by means of sterile pipettes with a drop or two of spore suspension. The cultures were killed by adding 10 cc. of 10 per cent HCl to each flask. The cultures were then filtered off on tared Gooch crucibles prepared with asbestos, washed until acid free, and brought to constant weight in a Freas electric oven at 100° C., and the dry weight determined. It was found impossible at times to filter luxuriant cultures of *F. oxysporum* by this method, because of the tenacity with which this organism holds water. Consequently they were filtered on soft filter paper, transferred to tared Gooch crucibles, dried, and weighed. The other organism holds water with little tenacity and filters with ease.

In all of experiments given below the following stock mineral solution was used: 20 gm. NH_4NO_3; 10 gm. KH_2PO_4; 5 gm. $MgSO_4$ per 1000 cc. H_2O. When carbohydrates were employed,

TABLE I

DRY WEIGHT (IN MILLIGRAMS) AFTER 20 DAYS' GROWTH IN POTATO EXTRACT MEDIUM; ROOM TEMPERATURE

	FUSARIUM OXYSPORUM					
	Temperature					
	35°	30°	25°	12°	1°.11*	—1°.11*
Flask 1	40	55	63	64	62	86
Flask 2	47	78	68	66	....	....
Flask 3	61	86	80	68	....	....
Average	49	73	70	66	62	86

	FUSARIUM TRICHOTHECIOIDE					
	Temperature					
	35°	30°	25°	12°	1°.11*	—1°.11*
Flask 1	0	0	60	87	146	83
Flask 2	0	0	64	100	....	....
Flask 3	0	0	65	147	....	....
Average	0	0	63	111	146	83

*For 20 days (no growth), then at 25° C. for 25 days.

these were added at the rate of 10 gm. per liter. Potato extract medium was made up by extracting 500 gm. ground potato tuber with 500 cc. H_2O, and then adding 500 cc. of the foregoing solution to the extract.

A series of cultures (table II) was run at 12° C. and the amount of dry weight formed determined at 2 day intervals for 10 days. In this series the medium was at 12° C. at the time of inoculation.

TABLE II

DRY WEIGHT (IN MILLIGRAMS) IN POTATO EXTRACT MEDIUM; TEMPERATURE 12° C.

	FUSARIUM OXYSPORUM					FUSARIUM TRICHOTHECIOIDES				
	Number of days					Number of days				
	2	4	6	8	10	2	4	6	8	10
I	0.2	0.4	5.2	.....	13.2	1.4	4.0	9.4	.....	27.0
II	0.6	0.4	5.6	.....	13.0	1.8	4.4	12.2	.....	44.6
Average	0.4	0.4	5.4	.....	13.1	1.6	4.2	10.8	.....	35.8

Table III shows the growth by day intervals made for 10 days when levulose was used as the carbon source. The solutions were at the temperatures indicated at the time of inoculation.

TABLE III

DRY WEIGHT (IN MILLIGRAMS) FORMED BY DAY INTERVALS

	FUSARIUM TRICHOTHECIOIDES AT 25° C.									
	Number of days									
	1	2	3	4	5	6	7	8	9	10
I	0.2	0.6	4.2	12.8	29.0	19.2	25.4	19.4	34.0	43.6
II	0.2	2.4	18.0	31.6	32.4	34.2	27.2	41.9	47.7	50.8
Average	0.2	1.5	11.1	22.2	30.7	26.7	26.3	30.6	40.8	47.2

	FUSARIUM OXYSPORUM AT 25° C.									
	Number of days									
	1	2	3	4	5	6	7	8	9	10
I	0.4	1.8	9.2	16.0	23.6	19.6	24.0	24.1	30.9	37.0
II	0.8	3.2	10.8	29.2	33.4	21.2	27.5	26.0	34.8	38.8
Average	0.6	2.5	10.0	22.6	28.5	20.4	25.7	25.0	32.8	37.9

TABLE III—*Continued*

	Fusarium oxysporum at 30° C.									
	Number of days									
	1	2	3	4	5	6	7	8	9	10
I	1.0	3.6	15.4	17.8	37.6	45.8	55.8	66.0	78.2	62.2
II	8.9	5.2	17.6	19.0	40.2	77.8	62.6	69.6	78.6	66.6
Average	4.9	4.4	16.5	18.4	38.9	61.8	59.2	67.8	78.4	64.4

	Fusarium trichothecioides at 25° C.									
	Number of days									
	1	2	3	4	5	6	7	8	9	10
Average	4.4	19	67.4	....	....	....	....	262	....	....

	Fusarium oxysporum at 30° C.									
	Number of days									
	1	2	3	4	5	6	7	8	9	10
Average	11.2	48	108.6	....	....	....	....	240.2	....	....

These tables show a tendency of *F. trichothecioides* to make a greater initial growth at low temperatures. At higher temperatures, however, unless above the optimum of *F. trichothecioides, F. oxysporum*, even though it made the greater initial growth, was soon overtaken and passed by *F. trichothecioides.* This was especially marked when dextrose and levulose were used as carbon source. This may be the result of a faster though more superficial feeding of *F. oxysporum*, which makes it unable to use materials as thoroughly as the other organism. This phenomenon is hardly a case of more rapid intoxication on the part of *F. oxysporum.*

The results obtained with artificial media were verified by infection experiments conducted with potato tubers kept at various temperatures. Tubers of the Red Cobbler variety were used. These were inoculated on April 1, and examined on May 27 (table IV). See figs. 11 and 12.

It should be noted here that *F. trichothecioides* when inoculated into a tuber can grow at 30° C., while it cannot do so in artificial media; and that *F. oxysporum* can survive a temperature of 1° C. in artificial media, but not in the tuber.

TABLE IV

CONDITION OF TUBERS AT CLOSE OF EXPERIMENT

Temperature	Fusarium oxysporum	Fusarium trichothecioides
30° C.	All completely rotted; sprouts killed	Slight rot in some
25° C.	All completely rotted; sprouts killed	All completely rotted; some sprouts killed
12° C.	All with very slight rot	All completely rotted
1° C.	No rot	All with slight rot
1° C. for two weeks, then 25° C. for two weeks	Slight rot in one tuber	All completely rotted
—1° C.	No rot	No rot
—1° C. for two weeks, then 25° C. for two weeks	No rot	All completely rotted

Discussion.—These results may, in part at least, explain why *F. oxysporum*, even though it can attack parenchyma and rot tubers, usually is not found in rotted tubers, while *F. trichothecioides* is. The ability of the latter to make a faster initial growth at the temperatures which prevail in the soil about digging time and in well kept storage places is probably the determining factor in this phenomenon. The experiments with tubers showed that *F. trichothecioides* made a great increase in growth rate when transferred from a low to a higher temperature.

These temperature relations may also explain in part the fact that we usually find *F. oxysporum* producing wilt under field conditions, and lend support to the observations made by ORTON (**27**), who reports potato wilt induced by *Fusarium* spp. to be pre-eminently a warm climate disease. *F. trichothecioides* can produce wilt, but the temperature conditions in the soil are such as to favor *F. oxysporum*, the maximum temperature of the former being the optimum of the latter. HUMPHREY (**15**), working in Washington on the tomato wilt induced by *F. oxysporum*, came to the conclusion that temperature differences in various parts of the state were determining factors for the appearance and non-appearance and severity of the disease.

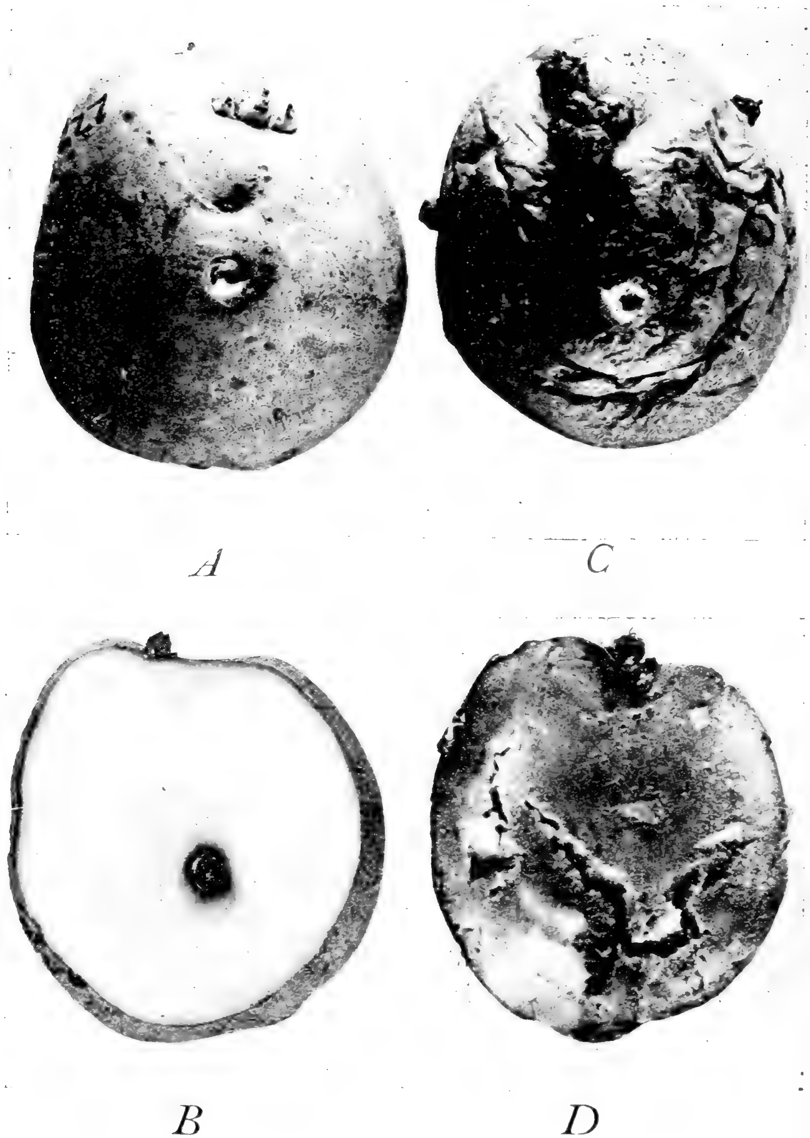


FIG. 11.—Tuber rot of Red Cobbler variety produced by inoculation with *Fusarium oxysporum; A, B*, external and sectional view of same tuber, incubated for 30 days at 12° C.; *C, D*, external and sectional view of same tuber, incubated for 30 days at 25° C.

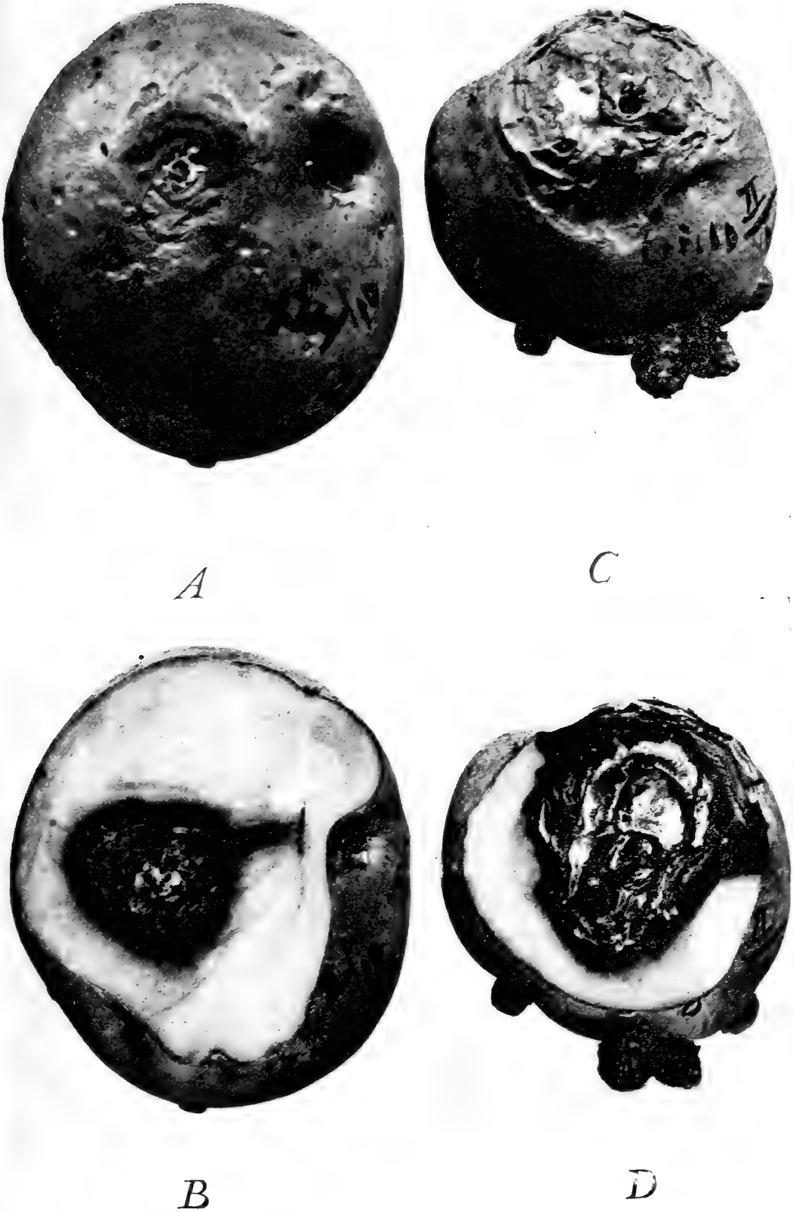
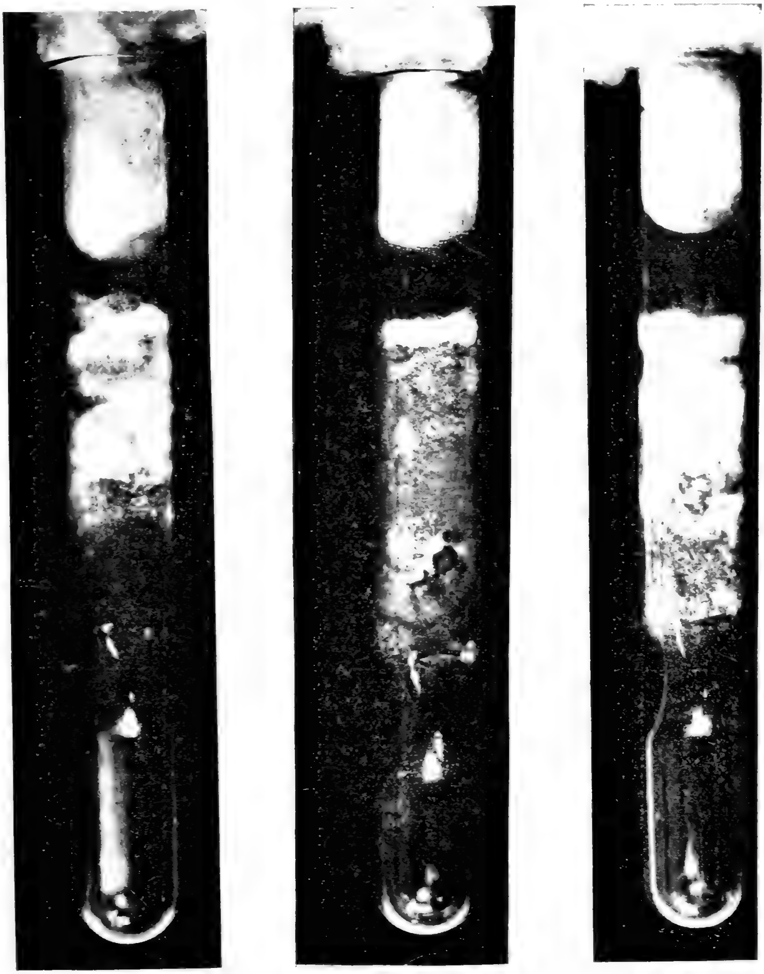


FIG. 12.—Tuber rot of Red Cobbler variety produced by inoculation with *Fusarium trichothecioides; A, B*, external and sectional view of same tuber, incubated for 30 days at 25° C.; *C, D*, external and sectional view of same tuber, incubated for 30 days at 12° C.

2. Growth habit.—It was observed in nearly all cultures that *F. oxysporum* not only made a greater initial growth at ordinary temperatures, but that it was at all temperatures much more of a surface grower than *F. trichothecioides*, making a superficial spreading growth, rather than the penetrating restricted intensive growth of the latter. Early sporulation was associated with the restricted growth habit of the latter (fig. 13). These habits were especially clearly marked on solid substrata, but even in liquid media *F. oxysporum* made a much less compact growth than the other species. It may be that the more spreading and extensive growth habit of *F. oxysporum* at all temperatures and its more rapid initial growth at temperatures above 10-15° C. are associated with a greater oxygen requirement than that possessed by *F. trichothecioides.* This would explain in part the frequenting of intercellular spaces and xylem elements by the former, and its consequent greater efficiency in causing vascular mycosis and wilt, as well as its tendency to cause bundle discoloration. The xylem elements of the stem end are undoubtedly infected while the tuber is yet in the soil, where temperature conditions are such as to favor the growth of *F. oxysporum.* Storage temperatures check the growth of this organism and the cells bordering the infected vascular elements shut the infected area off by suberizing their walls. Cultural experiments and microscopical studies show that cork is not absolutely impenetrable to these organisms, although it provides under normal conditions an effective barrier to the progress of both of these species. Because of the slower growth of *F. trichothecioides* at higher temperatures, the potato plant undoubtedly has a much better opportunity to guard itself by cork formation against this organism than against the other.

3. The carbon sources of the two organisms.—A difference in the metabolic requirements of two organisms, a difference in their ability to utilize various substances, or a difference in their ability to tolerate the presence of substances may be factors of critical importance in determining which of the two will attack a given tissue or a given plant. These factors may determine also the modes of attack of an organism upon a tissue or a plant. Thus an organism that can digest pectinaceous material and not cellulose

would have to destroy a tissue whose walls are mainly cellulose by intercellular activity, while one that could digest cellulose might



A B C

FIG. 13.—*Fusarium trichothecioides* and *F. oxysporum* on sterile potato cylinders; *A*, *C*, cylinders inoculated with *F. oxysporum*, incubated for 2 days at 25° C.; *B*, cylinder inoculated with *F. trichothecioides*, incubated for 2 days at 25° C.

destroy this tissue by a primary cell invasion. Again, a greater ability on the part of an organism to digest suberin, other things

being equal, would render it a much more formidable enemy of the potato plant than an organism without this ability, or possessing it to a less degree. This problem was attacked by making a study of the carbon sources of the organisms. The data reported here are only a beginning of this phase of the problem.

Fifty cc. of nutrient solution were measured quantitatively into 200 cc. Erlenmeyer flasks with a pipette. The flasks were then plugged with cotton, covered with tinfoil, and autoclaved. After cooling, 0.5 gm. of carbohydrate material was transferred quantitatively into each flask, and the flasks covered again with tinfoil and sterilized in a Freas oven by heating at 85° C. for one hour every 12 hours, for 6 consecutive days. The solutions were then incubated at 25° C. for 48 hours, so as to allow any contaminations present to appear. Low sterilization temperature was used to reduce hydrolysis of carbohydrates to a minimum.

The dry weight determinations were made by the methods outlined above. It was found advisable to kill two cultures of each set after 6 days, for the striking differences in rate of growth between the two organisms that were observed during the first 48-120 hours were obliterated by prolonged growth. The other 3 cultures were killed after 12 days' growth. The dry weight values do not show the differences in habit and rate of growth in the cultures as strikingly as they appeared to the eye. In many cases a visible growth was not determinable as dry weight. This is readily appreciated when we consider that moisture determinations indicated that the dry weight varied between 10 and 20 per cent of the wet weight.

In the controls, consisting of the plain mineral medium without carbon material, *F. oxysporum* made a weighable growth in 12 days, though not in 6 days, while *F. trichothecioides* made no weighable growth even after 12 days. Another important observation was made. In no case was it necessary to reinoculate with *F. oxysporum,* while many *F. trichothecioides* inoculations failed. The latter undoubtedly is the slower starter and much more poorly equipped for sure and quick infection than the former.

The figures in tables V-VIII represent milligrams of dry weight of material formed, except in those cases in which per cent is written. In such cases (cork, cellulose, and hemicellulose) the figures repre-

sent the percentage of decrease in dry weight of material. The last weighing in these cases unavoidably included the dry weight of fungus material formed, so that the figures are higher than they ought to be. The differences in weight in these cases give only comparative values of the amounts of material respired by the organisms. The filter paper used was the best Swedish paper, and the cork was obtained by skinning steamed potatoes, scrubbing the skin thoroughly, boiling it for 48 hours in distilled water, extracting for 48 hours in ether, and then boiling again with water. All figures represent averages, the composition of these figures being shown in tables VI and VII. In many cases there was a fair coincidence of the values, while in others a great disparity appeared. The averages probably would more nearly approximate the true value if a greater number of figures were available.

TABLE V

DRY WEIGHT (IN MILLIGRAMS) FORMED IN 6 AND 12 DAYS BY *Fusarium trichothecioides* AND *F. oxysporum*

	FUSARIUM TRICHOTHECIOIDES		FUSARIUM OXYSPORUM	
	Number of days		Number of days	
	6	12	6	12
Ethyl alcohol	....	1.2	15.0	18.5
Glycerine	12.0	20.5	17.0	92.0
Mannit	108.5	136.3	109.5	112.0
Arabinose	5.2	35.0	78.7	43.0
Glucose	11.5	42.3	43.5	44.0
Mannose	2.0	52.0	49.0	62.0
Galactose	28.8	43.3	39.0	73.0
Fructose	56.5	81.0	74.5	77.6
Saccharose	9.5	45.6	36.5	35.6
Maltose	13.0	61.0	35.5	50.3
Lactose	1.3	20.0	4.0	21.0
Raffinose	12.4	47.3	44.5	54.6
Potato starch	....	45.0 per cent	81.0	103.0
Wheat starch	22.6 per cent	42.1 per cent	54.3 per cent	127.0
Corn starch	19.7 per cent	33.4 per cent	37.9 per cent	67.2 per cent
Soluble starch	45.2 per cent	49.0 per cent	110.5	210.3
Dextrine	4.4	37.3	42.0	56.3
Inulin	63.6	123.0	102.0	90.0
Gum arabic	1.5	18.6	37.0	58.3
Gum tragacanth	67.5 per cent	14.1 per cent	27.1 per cent	25.7
Hemicellulose	10.1 per cent	7.3 per cent	10.1 per cent	6.7 per cent
Cellulose	4.0 per cent	1.0 per cent	4.25 per cent	6.7 per cent
Cork	10.1 per cent	5.9 per cent	12.8 per cent	3.9 per cent
No carbon source	....	....	....	0.5

Table V shows that qualitatively the two organisms behave alike in their ability to use all the carbon compounds tested. Quantitatively there is considerable difference, both as to rate of consumption and total growth after 12 days. *F. oxysporum* in general shows the greater speed of growth and greater growth after twelve days. In some cases *F. trichothecioides* shows the greater growth after 12 days.

TABLE VI

DRY WEIGHT (IN MILLIGRAMS) FORMED WHEN EACH FLASK RECEIVED 0.5 GM. OF MANNIT; CONCENTRATION 1 PER CENT

No. of flask	Fusarium oxysporum		Fusarium trichothecioides	
	6 days	12 days	6 days	12 days
I	93	....	107	....
II	126	....	110	....
III	....	108	....	130
IV	....	112	....	135
V	....	116	....	141
Average	109.5	112	108.5	136.3

TABLE VII

HEMICELLULOSE (IN GM.) USED IN 12 DAYS

No. of flask	Fusarium oxysporum			Fusarium trichothecioides		
	6 days			6 days		
	Grams of material	Decrease in weight	Percentage of decrease	Grams of material	Decrease in weight	Percentage of decrease
I	0.5055	0.0455	9.0	0.5213	0.0513	9.8
II	0.5154	0.0584	11.3	0.4964	0.0524	10.5
Average	....	....	10.1	....	....	10.1
	12 days			12 days		
III	0.5185	0.0355	6.1	0.501	0.028	5.5
IV	0.5192	0.0382	7.3	0.5058	0.0488	9.4
Average	....	....	6.7	....	....	7.3

Table VIII gives the dry weight formed by the organisms when carbon acids were furnished as carbon sources. N/100 solutions were used, excepting for asparagin and asparagenic acid, whose solu-

bility permitted only N/200 solutions. In the case of the higher fatty acids and oils, the material was weighed out as though N/100 solutions were being prepared. With these no weighings of the material formed were attempted, but merely differences in luxuriance of growth were recorded. To those acids which showed no growth with N/100 solutions, 5 cc. of 10 per cent glucose solution were added, making the sugar concentration 1 per cent, so as to determine whether the acid was merely non-usable, or whether it was toxic. Since it was found that some were toxic at N/100 concentration, lower concentrations were made up also. The results are given in table IX.

TABLE VIII

DRY WEIGHT (IN MILLIGRAMS) FORMED WITH THE FOLLOWING CARBON COMPOUNDS AS CARBON SOURCES

	FUSARIUM TRICHOTHECIOIDES		FUSARIUM OXYSPORUM	
	Number of days		Number of days	
	6	12	6	12
Formic acid N/100	None	None	None	None
+5 cc. 10 per cent glucose solution	"	"	"	85.5
Acetic acid N/100	"	"	1.2	10.6
+5 cc. 10 per cent glucose solution	"	106	None	None
Proprionic acid N/100	"	None	"	"
+5 cc. 10 per cent glucose solution	"	"	"	"
Butyric acid N/100	"	"	"	"
+5 cc. 10 per cent glucose solution	"	"	"	"
Glycocollic acid N/100	2.5	7.3	20.0	8.6
Lactic acid N/100	0.3	0.6	8.0	23.0
Oxalic acid N/100	Non-weighable	Non-weighable	Non-weighable	Non-weighable
Succinic acid N/100	Non-weighable	Non-weighable	8.5	9.3
Malic acid N/100	Non-weighable	Non-weighable	4.5	8.0
Tartaric acid N/100	1.0	0.93	6.0	4.3
Citric acid N/100	2.6	6.6	8.0	6.6
Aspartic acid N/200	1.6	....	5.5	6.5
Asparagin N/200	3.5	3.8	5.5	5.3
Tannic acid 1 per cent	1.0	31.0	0.2	42.0
Tannic acid 0.5 per cent	1.6	61.0	1.6	41.0
+5 cc. 10 per cent glucose	3.5	32.0	5.0	47.0
Control 0.5 gm. levulose	....	82.0	....	116.0

TABLE VIII—*Continued*

	FUSARIUM TRICHOTHECIOIDES		FUSARIUM OXYSPORUM	
	12 days		12 days	
Palmitic acid I	No	growth	Good	growth
" " II	Slight	"	"	"
" " III	"	"	"	"
" " IV	"	"	"	"
+5 cc. 10 per cent dextrose, V	Excellent	"	"	"
Stearic acid, I	Slight	"	"	"
" " II	No	"	"	"
" " III	"	"	"	"
" " IV	"	"	"	"
+5 cc. 10 per cent dextrose, V	Excellent	"	"	"
Oleic acid, I	No	"	"	"
" " II	Poor	"	"	"
" " III	"	"	"	"
" " IV	"	"	"	"
+5 cc. 10 per cent dextrose, V	Slight	"	"	"
Palm oil, I	No	"	No	"
" " II	"	"	"	"
" " III	"	"	"	"
" " IV	"	"	"	"
+5 cc. 10 per cent dextrose, V	"	"	"	"
Olive oil, I	Fair	"	Fair	"
" " II	"	"	"	"
" " III	"	"	"	"
" " IV	"	"	"	"

A marked difference was found in the ability of the two organisms to use the fatty acids, *F. trichothecioides* being much more restricted in its ability. The experiments with alcohol and the acids also showed that the former organism was much more readily poisoned and inhibited in its growth. It was found that *F. oxysporum* grew well in 1 per cent ethyl alcohol, and that *F. trichothecioides* made no growth. The solution was then diluted one-half, whereupon *F. trichothecioides* made a good growth. This was clearly a case of inhibition. The growth of *F. trichothecioides* was inhibited by N/100 acetic acid, as can be seen by the fact that it grew in N/125 concentration and that it grew in N/100 when glucose was added, while *F. oxysporum* grew well in N/100 acetic acid. N/100 formic acid was toxic to *F. trichothecioides,* while it merely inhibited growth with the other organisms. The latter grew in N/125 formic acid, while *F. trichothecioides* did not grow in N/500 solution. N/100 proprionic acid was toxic to both, while both

grew in N/250 solution. N/250 butyric acid was toxic to *F. trichothecioides,* while *F. oxysporum* grew in it.

TABLE IX

DRY WEIGHT (IN MILLIGRAMS) FORMED IN 12 DAYS IN VARIOUS CONCENTRATIONS OF ACID

Concentration	Fusarium oxysporum				Fusarium trichothecioides			
	N/1000	N/500	N/250	N/125	N/1000	N/500	N/250	N/125
Formic acid								
I	Non-weighable	Non-weighable	Non-weighable	Non-weighable	Non-weighable	None	None	None
II	Non-weighable	Non-weighable	Non-weighable	Non-weighable	Non-weighable	"	"	"
Average	......	......	......	......	......	......	......	......
Acetic acid								
I	......	......	......	......	0.8	1.2	3.2	5.8
II	......	......	......	......	0.8	2	3.4	6.6
Average	......	......	......	......	0.8	1.6	3.3	6.2
Proprionic acid								
I	1.4	2.0	5.0	None	1.4	2.6	4.0	None
II	2.6	2.4	5.8	"	1.2	3.4	6.6	"
Average	2.0	2.2	5.4	......	1.3	3.0	5.3	......
Butyric acid								
I	4.8	7.6	10.4	None	2.4	5.0	None	None
II	5.4	9.0	13.8	"	3.6	5.6	"	"
Average	5.1	8.3	12.1	......	3.0	5.3	......	......
Oxalic acid								
I	0.4	0.4	0.4	1.2	0.8	Non-weighable	Non-weighable	Non-weighable
II	0.8	1.2	1.2	1.2	0.8	Non-weighable	Non-weighable	0.2
Average	0.6	0.8	0.8	1.2	0.8	......	......	0.1

A set of experiments was run also in which solanin in various percentages was added to glucose media. Because of the high cost of solanin, only 1 cc. solution was used in each test. The results are given in table X.

These differences, that is, greater versatility in the use of carbon sources, greater resistance to inhibition, and intoxication, may well

play an important role in determining the difference in behavior of these two organisms.

TABLE X

DRY WEIGHT (IN MILLIGRAMS) FORMED BY *Fusarium oxysporum* AND *F. trichothecioides* IN 6 DAYS

	Percentage solanin				
	1	2	0.25	0.226	0
Fusarium oxysporum	10.6	8.1	13.2	10	13.8
Fusarium trichothecioides	2.5	2.4	7.8	....	9.3

Discussion.—The versatility of these organisms in using various carbon sources in their metabolism is of great interest. This almost omnivorous ability to use carbon compounds, including the simplest fatty acid, the highly oxidized fatty acids, the long carbon chain acids, the alcohols, mono- and poly-hydric, glycerin and fats, the mono-, di-, and poly-saccharides, including the dextrines, starches, hemicelluloses, and true celluloses, assigns to them an important role in the carbon cycle, and at the same time must help render them the formidable and destructive enemies of the root crops that they are.

The methods suggested by APPEL (**2**), namely, rigid inspection of potato fields, immediate destruction of all plants that show the slightest symptoms, quarantining of non-certified seed stock, alone give promise of keeping these troubles in check. Disinfection of storage cellars and of potatoes when put into storage, together with storage at proper temperature, will help combat these diseases, especially the dry rot induced by *F. trichothecioides*.

Conclusions

1. *Fusarium tuberivorum* WILCOX and LINK is the same as *Fusarium trichothecioides* WOLL.

2. Both *Fusarium oxysporum* and *F. trichothecioides* can produce both tuber rot and wilt of the potato plant.

3. The wilt is induced by destruction of the root system and by clogging of the xylem elements in the stem, and is, in mild cases, marked by such symptoms as discoloration of leaves, curling and rolling of leaves, and production of aerial tubers.

4. Under field and storage conditions *Fusarium oxysporum* is more probably responsible for wilt than is *F. trichothecioides,* and the latter more responsible for tuber rotting.

5. The optimum and maximum temperatures of *Fusarium oxysporum* are higher than those of *F. trichothecioides. F. trichothecioides,* however, grows well at 8–10° C., while *F. oxysporum* does not. These facts may explain in part the fact that *F. oxysporum* produces more wilt than *F. trichothecioides,* and that the latter causes more tuber rot.

6. *Fusarium oxysporum* has a more rapid, superficial, and spreading habit of growth than has *F. trichothecioides.* This may be associated with a greater oxygen requirement for *F. oxysporum,* and may account for the frequenting of xylem elements by this fungus.

7. Both organisms possess a striking ability to use the most diverse carbon materials as carbon sources in their metabolism. *Fusarium oxysporum* has a greater range in its ability, and can utilize the materials more readily, although not so completely as does *F. trichothecioides.*

8. *Fusarium oxysporum* is less subject to inhibition in growth and intoxication than is *F. trichothecioides.*

9. Solanin is not toxic to either organism, although it seems to inhibit somewhat the growth of *Fusarium trichothecioides.*

The writer acknowledges his indebtedness to Dr. E. Mead Wilcox and to Dr. William Crocker. They not only made this research possible, but they gave freely of advice and criticism, and lent encouragement by their interest in the progress of the investigation.

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LITERATURE CITED

1. Appel, Otto, Untersuchungen über die Schwarzbeinigkeit und die durch Bakterien hervorgerufene Knollenfäule der Kartoffel. Arb. Biol. Abth Land- u. Forstw. Kais. Gesund. 3:362-432. *pl. 1. figs. 1-15.* 1903.
2. ———, Leaf roll diseases of the potato. Phytopathology 5:139-148. 1915.

3. Appel, O., and Kreitz, Wilhelm, Untersuchungen über die Schale verschiedener Kartoffelsorten und ihre Beeinflussung durch Bodenverhältnisse, Feuchtigkeit und Düngung. Arb. Kais. Biol. Anst. Land- u. Forstw. 6:1-27. *pls. 2. figs. 1-10.* 1908.
4. Appel, O., and Schlumberger, Otto, Die Blattroll Krankheit und unsere Kartoffelernten. Berlin. pp. 102, *pls. 3.* 1911. This contains a complete bibliography.
5. Appel, O., and Wollenweber, H. W., Grundlagen einer Monographie der Gattung *Fusarium* (Link). Arb. Kais. Biol. Anst. Land- u. Forstw. 8:1-207. *pls. 4. figs. 1-2.* 1910.
6. Bary, A. De, Die gegenwärtig-herrschende Kartoffelkrankheit, ihre Ursache, und ihre Verhütung. Eine pflanzenphysiologische Untersuchung in allgemein verständlicher Form dargestellt. Leipzig. pp. 755. 1861.
7. Carpenter, C. W., Some potato tuber-rots caused by species of *Fusarium.* Jour. Agric. Research. Dept. Agric. 5: no. 15. 183-209. *pls. 7.* 1915.
8. Corsault, J .H., Studies of the *Rhizoctonia* disease of potatoes. Phytopathology 5:293-294. 1915.
9. Drayton, F. L., The *Rhizoctonia* lesions on potato stems. Phytopathology 5:59-63, *pl. 1, fig. 1,* 1915.
10. Duggar, B. M., Fungous diseases of plants, with chapters on physiology, culture methods, and technique. Boston. 1909.
11. Frank, A. B. Die Krankheiten der Pflanzen. Breslau. 1896.
12. ———, Untersuchungen über die verschiedenen Erreger der Kartoffelfäule. Ber. Deutsch. Bot. Gesells. 16:273-280. 1898.
13. Gloyer, W. O., The efficiency of formaldehyde in the treatment of seed potatoes for *Rhizoctonia.* Bull. no. 370. N.Y. Exp. Sta. 417-431. 1913.
14. Hasselbring, The carbon assimilation of *Penicillium.* Bot. Gaz. 45:176-193. 1908.
15. Humphrey, H. B., Studies on the relation of certain species of *Fusarium* to the tomato blight of the Pacific Northwest. Bul. State Coll Wash. Agric. Exp. Sta. no. 115, pp. 21. *pls. 5.* 1914.
16. Jamieson, C. O., and Wollenweber, H. W., An external dry rot of potato tubers caused by *Fusarium trichothecioides* Wollenw. Jour. Wash. Acad. Sci. 3:146-152. *fig. 1.* 1912.
17. Jones, L. R., Potato diseases in Wisconsin and their control. Circ. of Information. Wis. Exp. Sta. 36:1-10. 1912.
18. Lindau, G., Die pflanzlichen Parisiten. Sorauer's Hand. d. Pflanzenkr. 2:pp. 550. *figs. 62.* 1908.
19. Link, Geo. K. K., Studies of a *Fusarium* causing dry rot of Irish potatoes. Thesis. Univ. of Neb. May 1912.
20. Link, H. F., Observationes in ordines plantarum naturales. Mag. Gesells. Naturf. Freunde 2:3-42. 1809.
21. ———, Species Hyphomyceten et Gymnocetum. Pars 1. 1824.

22. Longman, Sibyl, The dry rot of potatoes. Jour. Linn. Soc. Bot. 39:120-129. *pl. 1.* 1909.
23. Lounsbury, C. P., Dry rot of the potato. Agric. Jour. Cape Good Hope 35:42-48. *figs. 31.* 1909.
24. Manns, Thos. F., The *Fusarium* blight and dry rot of the potato. Bull. no. 229. Ohio Exp. Sta. 299-336. *pls. 1-15.* 1911.
25. Massee, G., Textbook of plant diseases. London. 1904.
26. Morse, W. J., and Schapovalov, M., The *Rhizoctonia* disease of potatoes. Bull. no. 230. Maine Exp. Sta. 1914.
27. Orton, W. A., Potato wilt, leaf roll, and related diseases. Bull. no. 64. U. S. Dept. Agric. pp. 49. *pls. 16.* 1914.
28. Pethybridce, G. H., and Bowers, G. E. H., Dry rot of the potato tuber. Econ. Proc. Roy. Dublin Soc. 1:547-558. *pls. 48.* 1908.
29. Pizzigoni, A., Cancrena secca ed unida delle patate. Nuovo Giov. Bot. Ital. 3:50-53. 1896.
30. Reinke, J., and Bertholdt, G., Die Zersetzung der Kartoffel durch Pilze. Untersuch. Bot. Lab. Univ. Göttingen, Berlin, 1879.
31. Rolfs, F. M., Potato failures. A preliminary report. Bull no. 70. Colo. Agric. Exp. Sta. pp. 19. *pls. 12.* 1902.
32. ———, Potato failures. A second report. Bull no. 91. Colo. Agric. Exp. Sta. pp. 33. *pls. 5.* 1904.
33. Sherbakoff, C. D., Fusaria of potatoes. Memoir. Cornell Univ. Agric. Exp. Sta. 6:90-270. *pls. 7.* 1915.
34. Smith, E. F., Wilt disease of cotton, watermelon, and cowpea (*Neocosmospora,* n. gen.). Bull. U. S. Dept. Agric. Div. Veg. Phys. and Path. 17:1-26. *pls. 10.* 1899.
35. Smith, E. F., and Swingle, D. B., Dry rot of potatoes due to *Fusarium oxysporum*. Bull. no. 55. Bur. Pl. Ind. U. S. Dept. Agric. pp. 64. *pls. 8. figs. 2.* 1904.
36. Sorauer, Paul, Pflanzenkrankheiten. Berlin. 1886.
37. Stewart, F. G., and Gloyer, W. O., The injurious effect of formaldehyde gas on potato tubers. Bull. no. 369. N. Y. Agric. Exp. Sta. 385-416. *pls. 3.* 1913.
38. Wehmer, C. Uber die Ursache der sogenannten "Trockenfäule" der Kartoffelknollen. Ber. Deutsch. Bot. Gesells. 14:101-107. *figs. 3.* 1896.
39. ———, Ansteckungsversuche mit *Fusarium Solani* (Die *Fusarium* Fäule). Centrallbl. Bakt. u. Par. 5:727-743. *pls. 10, 11.* 1897.
40. Wilcox, E. M., Link, Geo. K. K., and Pool, V. W., A dry rot of the Irish potato tuber. Research Bull. Neb. Agric. Exp. Sta. 1:pp. 88. *pls. 28.* 1913.
41. Wollenweber, H. W., Studies on the *Fusarium* problem. Phytopathology. 3:24-50. *pls. 5. fig. 1.* 1913.
42. ———, Pilzparasitäre Welke-Krankheiten der Kulturpflanzen. Ber. Deutsch. Bot. Gesells 31:17-34. 1913.

[4-12-'17—1M.]

RESEARCH BULLETIN NO. 10

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

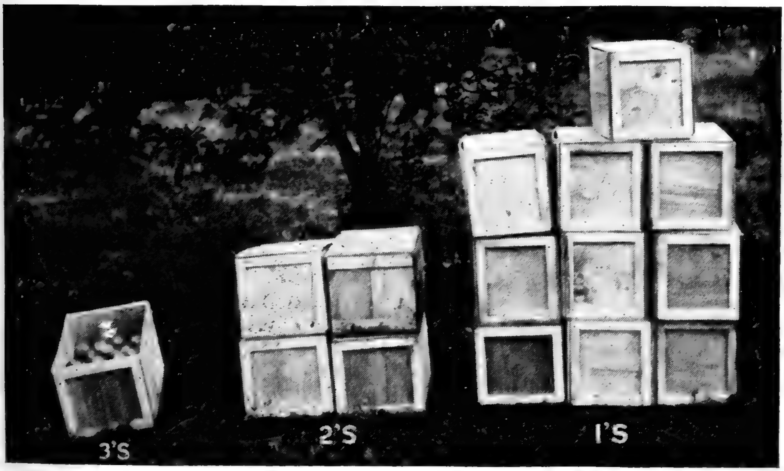
OF

NEBRASKA

SPRAYING EXPERIMENTS IN NEBRASKA

BY J. RALPH COOPER

DISTRIBUTED APRIL 10, 1917



FRUIT FROM A SPRAYED TREE GRADED INTO FIRSTS, SECONDS, AND THIRDS

LINCOLN, NEBRASKA
U. S. A.

AGRICULTURAL EXPERIMENT STATION OF NEBRASKA

CONTENTS

SPRAYING EXPERIMENTS IN NEBRASKA

J. RALPH COOPER

INTRODUCTION

Spraying experiments were begun in Nebraska in 1906 by the Experiment Station in coöperation with the United States Department of Agriculture. The results of the first year's work were published in Bulletin 98, "Spraying Demonstrations in Nebraska Apple Orchards." In 1907 the Experiment Station continued the work alone and published the results in Bulletin 106, "Does It Pay to Spray Nebraska Apple Orchards?" In 1908 the Experiment Station and the United States Department of Agriculture again conducted the work jointly, and in 1909 and 1910 the Experiment Station continued the work alone. A report of this work was made in Bulletin 119, "Spraying as an Essential Part of Profitable Apple Orcharding."

In 1913 work was begun on a much larger scale by the Experiment Station coöperating with the Extension Service in an attempt to demonstrate known methods and evolve new methods of practice from a commercial as well as an experimental standpoint and which would apply to the solution of spraying problems as they might arise from time to time.[1]

The more important questions which were considered during the three years covered by the present report were as follows:

1. How many summer sprays are required and when should they be applied?
2. What is the difference in efficiency between various brands of arsenate of lead?
3. What are the relative values of lime sulphur and Bordeaux as fungicides for spraying apples?
4. Is it possible to lessen or prevent Bordeaux injury and at the same time control fungous diseases?
5. Is it possible to interchange Bordeaux and lime sulphur in a spray schedule in such a manner as to secure better results than by using either fungicide for the complete schedule?
6. Is home boiled lime sulphur as efficient as the ordinary commercial brands of concentrated lime sulphur?
7. Of what value are certain new fungicides and insecticides as summer sprays for apples?

[1]The work was placed directly in charge of the writer, three-quarters of his salary being paid by the Experiment Station and one-quarter of his salary and all traveling expenses being paid by the Extension Service. The Extension Service also paid the salaries and traveling expenses of the assistants, while the Experiment Station furnished all materials not furnished by the orchard owners.

8. In what manner should the spray be applied,—as a fine mist or as a coarse, driving spray?

9. Does it pay, commercially, to use both an insecticide and a fungicide at every application?

10. Are the effects of spraying noticeable for longer than one season; i. e., are they cumulative?

11. What effect does clean culture have on disease and insect control?

12. What capacity machine is most economical for the various sizes of orchards ranging from the small home orchard to the largest commercial orchards?

ORGANIZATION

In order to secure results which would be thoroly reliable, it was deemed necessary to conduct field experiments in orchards located in different parts of the State and in a number sufficient to include as nearly as possible all the different conditions under which fruit growing is carried on. In order to overcome seasonal differences, it was planned to conduct experiments in these representative districts for a series of years.

Six orchards were selected in 1913,—one at Wymore owned by Lake Bridenthal; one at Nemaha, owned by John Smith; one at Brownville, owned by Fred Lewis; one at Florence, owned by J. J. Smith; one at Florence, owned by L. Abbott[1]; and the Experiment Station orchard at Lincoln.

In 1914 the orchards at Wymore and Brownville were retained and new ones selected, as follows: One at Beatrice, owned by E. J. Kessler; one at Lincoln, operated by A. N. Ohler; and one at Seward, owned by Allen Hickman.

In 1915 the orchards at Beatrice and Lincoln were retained and one new one selected near Omaha, owned by G. H. Beavers.

In all cases the work was done in coöperation with the orchard owners. At Beatrice and Wymore the work was done in coöperation with County Agricultural Agent O. H. Liebers and at Seward with County Agricultural Agent A. H. Beckhoff.

In 1913 the writer was assisted in the work by H. W. Richey, a graduate of the University of Nebraska; in 1914 by W. W. Downing, a graduate of Iowa State College; and in 1915 by E. H. Hoppert, a graduate of the University of Wisconsin, now Extension specialist with the University of Nebraska. The accompanying map shows the location of the various experiments conducted during the last three years.

In choosing the orchards, special care was taken to secure those representative of the sections in which they were located, which

[1]The data taken in Mr. Abbott's orchard were not used, because part of the fruit was picked by mistake and no records were kept.

were of uniform vigor and variety, and which were of such size and shape and planted in such a way that they would lend themselves to platting for experimental work.

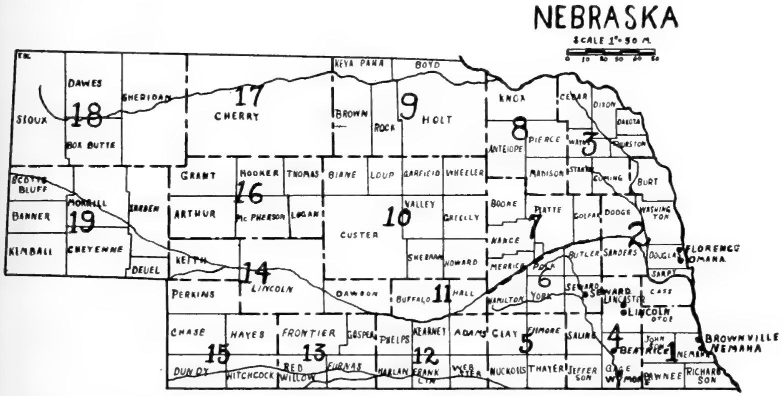


Fig. 1—Map showing location of experimental orchards

In order that the results might be thoroly reliable, and to overcome individual variation, a large number of trees were included in each plat, the number being in each case what could be conveniently sprayed with one load, except in cases where barrel sprayers were used, when two or more barrels of spray were used on the same plat. After the fruit was set, from four to twelve trees were selected, as nearly uniform in all respects as possible, from which to examine the fruit.

Trees were left unsprayed in each plat as a "check"[1] whenever possible. It was necessary to select the "check" trees before the fruit set and before the selection of the "count"[2] sprayed trees, but enough were left in practically all cases so that those which were not comparable could be discarded.

However, in spite of the utmost care, difficulties presented themselves from time to time. One of the greatest difficulties lay in the individual variation of trees. Another difficulty was the very noticeable variation in amount of disease infection and insect infestation in various parts of the same orchard. To counteract these variations, "checks" and "count" trees were selected as near together as possible in various places thruout the plats.

[1] "Checks" are the trees which were not sprayed.

[2] "Count" trees are those which were selected for special observation, the fruit being examined and counted for records.

It was very difficult to spray all of the trees exactly alike. To overcome this difficulty, one of the above mentioned men or the writer was present and directly supervised the weighing, mixing, and application of each spray for every plat.

Perhaps one of the greatest troubles encountered was the adoption of a uniform system of taking data and making records. The many degrees of insect, fungous, and spray injuries make it very difficult for different men to make uniform records because of different degrees of importance they may attach to each. This was overcome to a great extent by the writer working with each man thruout as much of the season as possible.

Especially during the season of 1915, russet appeared on the fruit of the check trees so that it was sometimes hard to distinguish between this and spray injury. Often where two unsprayed trees of the same variety stood side by side the fruit on one would be russeted and that on the other comparatively free. An attempt was made to overcome this by averaging the amount of russet on unsprayed trees, accepting this as a standard, and calling all over this amount, on the sprayed trees, spray injury.

INSECTS AND DISEASES CONSIDERED

The principal insects affecting apples in Nebraska are the codling moth (*Carpocapsa pomonella*) and the plum curculio (*Conotrachelus nenuphar*). There are numerous other foliage and fruit eating insects of minor importance, but they are controlled incidentally by the sprays intended for the former. The principal diseases affecting apples are apple scab (*Venturia inaequalis*) and apple blotch (*Phyllosticta solitaria*). As in the case of insects, there are many diseases of minor importance affecting the fruit and foliage of the apple which are usually controlled by sprays intended for the two principal diseases.

Occasionally serious outbreaks of cedar rust (*Gymnosporangium macropus*) occur in localities where large numbers of cedar trees are found near the orchards, but during the last three seasons practically no cedar rust has been noted. In wet seasons, sooty blotch (*Leptothyrium pomi*) often causes considerable damage.

TERMINOLOGY AND EXPLANATION

Bordeaux—The term "Bordeaux" is used thruout this report in place of Bordeaux mixture.

Lime sulphur—The term lime sulphur is used in place of lime sulphur solution.

In all tables Bordeaux is indicated by the letters Bx, lime sulphur by LS, arsenate of lead by Pb.

In indicating the formula when Bordeaux is used, 50 gallons

is the unit adopted, and the amount of the ingredients, expressed in pounds, precedes these figures, separated by dashes. The amount of copper sulphate is expressed first, then the amount of lime, and coming last the figures which show the total amount of solution; thus, Bx–3–4–50 indicates that three pounds of copper sulphate and four pounds of lime were diluted to 50 gallons, while $\frac{\text{Bx–Pb}}{\text{3–4–2–50}}$ indicates that two pounds of arsenate of lead was used with the Bordeaux.

In indicating the formula for lime sulphur, the same total unit, 50 gallons, is used, and either the amount of lime sulphur is expressed in gallons, or the total amount of solution is not mentioned and the strength of the solution, diluted and ready for use, is indicated by specific gravity; thus, LS–1½–50 indicates that one and one-half gallons of commercial lime sulphur was diluted to 50 gallons, while $\frac{\text{LS–Pb}}{1\frac{1}{2}\text{–2–50}}$ indicates that two pounds of arsenate of lead was used in the solution. By the specific gravity method, LS 1.009 indicates that the commercial lime sulphur was diluted until the specific gravity, as registered by a hydrometer, is 1.009 while $\frac{\text{LS–Pb}}{\text{1.009–2}}$ indicates that two pounds of arsenate of lead is added to each 50 gallons of the solution. When arsenate of lead alone is used, the formula is indicated by Pb–2–50.

For the sake of convenience, certain terms are used to designate the spray applications made at different times of the season. The first summer spray, which is applied before the trees are in bloom, is called the cluster-bud spray. The second, which is applied just after the petals have fallen, is called the petal-fall spray. The other applications are called the 7-days spray, the 14-days spray, the 21-days or 3-weeks spray, the 35-days spray, the second-brood spray, and the third-brood or fall spray. The names of the last two indicate that they are for the control of codling moth. This is usually but not always true. In some cases they are solely for the control of fungous diseases but in this report they are in all cases designated as above, regardless of the purpose for which they were employed.

METHODS EMPLOYED

The methods used in attempting to control these insects and diseases were based upon the accumulated experience of workers along this line in all parts of the United States. The machinery, materials, and time and manner of application will be discussed in the report of each experiment.

RECORDS OF RESULTS

In securing data from the various experiments during the years 1913, 1914, and 1915, over one million apples were counted. During the seasons of 1913 and 1914 every apple which set on the trees under observation was examined.[1] In 1915, on account of the extremely heavy set, only a part of the apples from each tree was examined. In examining the windfalls, one hundred apples were picked up under each of four sections of the tree and minutely examined.[2] All the remaining apples under the tree were picked up and counted, but not examined. To avoid error, all fruits around a certain spot were taken until a hundred had been secured. If there were less than four hundred windfalls, all were examined. At every succeeding examination the places from which apples were picked for examination were changed, so that at several times during the season windfalls from every part of the tree were examined. At picking time, one bushel of fruit was taken from the north, east, south, and west sides and from the top of the tree for examination, and the remaining apples were counted. In computing results, the total number of fruits on the tree were considered at the different percentages of infection or infestation found on the examined portion. Examinations of windfalls and notes on foliage were made as nearly as possible every two weeks from the first part of July until the fruit was harvested.

In examining fruit for blemishes every insect, fungous, or spray injury which would bar an apple from a No. 1 grade was recorded. In grading, the standard adopted by the Department of Horticulture, University of Nebraska, was adhered to.[3]

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[1]In examining the apples each one was cut open to be sure no worms were inside.

[2]Owing to the fact that both insects and fungous diseases operate as a rule early in the season and gradually cease their activities, together with the fact that injured fruit has a tendency to drop early, any records which do not take into account windfalls as well as picked fruit are not a reliable indication of the true conditions.

[3]*First Grade*—For larger varieties, such as Jonathan, Ben Davis, Black Twig, Arkansas Black, etc., $2\frac{1}{2}$-inch shall be the minimum size. The fruit must be free from insect, fungous, and mechanical injuries. The shape must be characteristic of the variety, and the apple must have $66\frac{2}{3}$ per cent of color for a perfectly colored apple of the variety for this region.

For small varieties, such as Winesap, Janet, Ingram, etc., $2\frac{1}{4}$ inches in diameter shall be the minimum size. The requirements otherwise shall be the same as for larger apples.

Fancy grades of all varieties shall be composed of those apples of the first grade which have 90 per cent color for a perfectly colored apple of the variety for this region.

Second Grade—The minimum size shall be $2\frac{1}{4}$ inches. Second grade apples shall possess the same physical requirements as to soundness and freedom from insect, fungous, and mechanical injury as the first grade apples.

Second grade apples may deviate slightly from the proper form and may show spray burn if not conspicuous. They must have $33\frac{1}{3}$ per cent color for a perfectly colored apple of the variety for this region.

Third Grade—Third grade apples, or salable culls, shall be made up of all apples not included in any of the above grades, free from decay and serious mechanical injury and measuring not less than two inches in diameter.

SPRAYING EXPERIMENTS FOR THE CONTROL OF INSECTS

CODLING MOTH

It has long been known that spraying with arsenical poisons at the proper seasons of the year will almost, if not quite, eliminate codling moth injury, and it is generally conceded that arsenate of lead is the best form in which to employ the poison. However, a great deal of discussion has arisen as to time and manner of application in order to secure the greatest efficiency.

In order to spray efficiently, a knowledge of the life history and habits of the insect is necessary. This knowledge was obtained by consulting the work of entomologists in this and other states, and by observations made as follows:

In the early spring, larvæ were collected from near-by orchards and from storage houses in Lincoln, placed in cotton stoppered test tubes and kept at a temperature equal to that of their natural habitat in the orchard. The tubes were examined every second day and notes taken on the duration of pupal stage, dates of emerging of moths, etc.

Six sprayed and six unsprayed trees were banded with burlap in such a way that the larvæ, either ascending or descending, would be trapped. These larvæ were collected and treated as stated above. In addition, careful notes were taken in the orchard on dates of appearance of moths, larvæ, and pupæ. Two mature trees were enclosed with window screening; and the moths collected were released inside, where they could be carefully studied and the larvæ collected so that reliable data could be obtained from which to determine the proper dates of application.

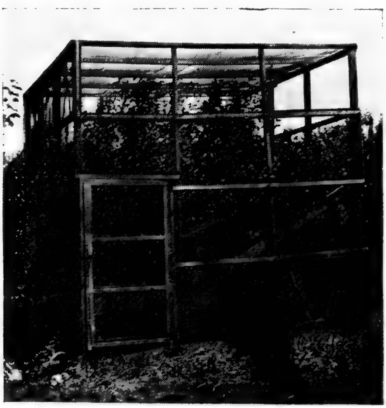


Fig. 2—Cage in which codling moths were studied

EXPERIMENTS IN 1913

In the spring of 1913, 213 larvæ were collected.[1] The first moth emerged on May 20, and the emergence reached its highest point June 5. The last moth emerged June 8. No doubt moths emerged in the orchard later than this. The first larva was found June 2. June 20 the larvæ appeared most numerous. The first pupa was found on June 24, and pupation reached its highest point on July 15. On July 10 the second-brood moths began to emerge and on July 25 the emergence had reached its highest point. On July 19 the first of the second-brood larvæ were found. The larvæ of this brood continued to emerge until frost, but diminished rapidly in numbers after August 25.

It was planned to apply the petal-fall spray at Lincoln May 6 to 10, or before the calyx cup of the first blossom to open began to close. Usually only one or two blossoms out of a cluster set fruit, and, as a rule, these are the buds which open first. Unless, because of adverse conditions, these first blossoms fail to become pollinated, they will be the first to close. Therefore, they are the ones which must be protected. The next spray was planned for May 25 to May 31, or just after the first-brood moths began to emerge, in order to be thru spraying just before the eggs began to hatch. The second-brood spray was planned for July 15 to 20, or just after the second-brood moths began to emerge. For the orchards south of Lincoln it was planned to apply each spray a few days earlier, and for those north, a few days later. However, it was found necessary to vary the dates somewhat.

The following diagram will indicate the comparative dates in the development of the codling moth at Lincoln, and the dates of spraying.

1913

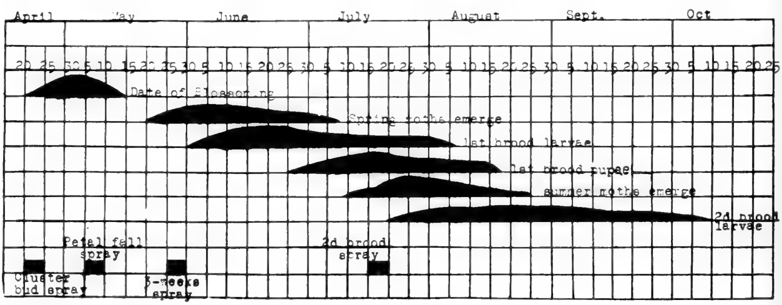


Fig. 3—Shows blooming period of apples, rate of development of codling moth, and dates when spraying was most effective for both codling moth and scab in 1913

[1] 97 of the larvæ perished.

The weather conditions were not quite normal in 1913. There was a great deal of rain very early in the season, but after the middle of June very little rain fell at Wymore, Brownville, or Lincoln. Conditions were better at Florence, but even there the rainfall was below normal. The hot, dry weather during the latter part of the season caused a heavy dropping of fruit, even where there was no injury.

In every case lime sulphur was used in combination with arsenate of lead, altho it does not appear in the schedules for codling moth. Also, in all cases 45° angle nozzles were used.

TABLE 1—*Wymore spray schedule*

Date Spray	April 21 Cluster-bud	May 5 Petal-fall	May 22 2-weeks	July 2 Second-brood
Plat 1.......	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Codling moth injury on windfalls and picked fruit

Varieties	Plat	Total fruit	Codling moth	Per cent
Ben Davis, Winesap, Jonathan	1	10,472	1,148	10.96
	check	2,203	1,080	49.02

At Wymore (table 1) during this season, a double acting hand pump similar to fig. 19 with two medium mist nozzles was used. At the petal-fall spray a pressure of 160 pounds was maintained. Considering the percentage of codling moth in the check plat as 100 per cent, this schedule was approximately 78 per cent efficient. The fact that 22 per cent of the "worms" found in the apples entered at the calyx indicates that the poison was not forced into all of them. This orchard had not been thoroly sprayed prior to this time.

TABLE 2—*Nemaha spray schedule*

Date Spray	April 23 Cluster-bud	May 7 Petal-fall	May 30 3-weeks	July 3 Second-brood	July 25 Third-brood
Plat 1.....	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50	....
2.....	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis......	1	2,180	218	10.00
Winesap........	1	2,941	286	9.72
Jonathan.......	1	2,751	246	8.94
	Total	7,872	750	9.53
Ben Davis......	2	1,834	64	3.49
Winesap........	2	1,887	58	3.07
Jonathan.......	2	2,751	95	3.45
	Total	6,472	217	3.35

Unfortunately the "check" trees were given the petal-fall application and are therefore not recorded.

At Nemaha (table 2), a power spray of 12-gallons-to-the-minute capacity, similar to fig. 23, was used. The petal-fall spray was applied with Bordeaux nozzles under a pressure of 250 pounds. All other applications were made with mist nozzles. It is unfortunate that we have no check with which to compare the sprayed plats. It is interesting to note that a spray applied 22 days after the regular second-brood spray reduced worm injury 6.18 per cent. Nearly 50 per cent of the larvæ entered at the calyx. The trees here were so tall that it was difficult to reach the tops, and no doubt a larger percentage of first-brood larvæ escaped than would have been the case with smaller trees. This orchard had never been sprayed before.

TABLE 3—*Brownville spray schedule*

Date Spray		May 8 Petal-fall	May 31 3-weeks	
Plat 1.......	....	Pb-2-50	Pb-2-50	....
2	....	....	....	....

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis	1	20,273	3,368	16.61
Mo. Pippin	check	1,804	1,298	71.95

At Brownville (table 3), a barrel pump similar to fig. 18 with one mist nozzle was used for the calyx application. For the next application a one-man power sprayer of 3- to 4-gallons-per-minute

capacity was used. Here the efficiency for the two sprays was 77 per cent. Slightly more than 50 per cent of the worms entered at the calyx. This orchard had never been sprayed before.

It was planned to apply four sprays, but the machinery was not received in time for the first spray and water could not be obtained for the second-brood spray.

TABLE 4—*Florence spray schedule*

Date Spray	April 24 Cluster-bud	May 10 Petal-fall	June 3 3-weeks	July 16 Second-brood
1	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis Winesap Jonathan	1 check	1,598 3,285	203 2,286	12.70 69.60

At Florence (table 4), a power sprayer of 10-gallons-to-the-minute capacity, similar to fig. 21, was used. The petal-fall spray was applied with Bordeaux nozzles at 225 pounds pressure. The efficiency of the schedule was 82 per cent. Slightly more than 43 per cent of the larvæ entered at the calyx. This orchard had never been sprayed before.

TABLE 5—*Lincoln spray schedule*

Date Spray	April 25 Cluster-bud	May 9 Petal-fall	June 2 3-weeks	July 15 Second-brood
Plat 1.......	Pb–3–50	Pb–3–50	Pb–3–50	Pb–3–50
2.......	....	Pb–3–50	....	....
3.......	Pb–3–50	Pb–3–50	Pb–3–50	....

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis Winesap Jonathan	1 2 3 check	2,549 2,234 3,762 3,530	273 396 501 1,172	10.71 17.73 13.32 33.20

At Lincoln the same capacity machine was used as at Nemaha. Mist nozzles were used for all applications. At the petal-fall spray a pressure of 250 pounds was maintained. The efficiency of the schedule for plat 1 was 68 per cent; for plat 2, 47 per cent; and for plat 3, slightly below 60 per cent. Forty per cent of the larvæ found in the fruit entered at the calyx.

The results of the first year's work on codling moth control indicate either (1) that the spraying was not thoroly done, (2) that the applications were not made at the right time, or (3) that the poison was not used in sufficient quantities.

There is no doubt that the spraying was done at the right time at Lincoln, where the closest observations of codling moth development were made.

That the poison was used in sufficient quantities is shown by the fact that the 2–50 formula, which was used in most cases, was as efficient as the 3–50 formula, as indicated in table 5. This will be discussed more fully under "a comparison of different brands of arsenate of lead."

It is evident that the spraying was not thoro. The fact that approximately 41 per cent of the larvæ found in the fruit entered at the calyx would indicate that the poison was not present in sufficient quantity, from not having been forced into the calyx cups. This lack of thoroness was for the most part unavoidable. The trees at Nemaha were so high that it was impossible to spray the tops from above. At Florence and Lincoln the wind was so strong that it was impossible to spray from but one direction. At Brownville and Wymore the pressure maintained during the petal-fall spray was irregular, hand power pumps being used at these places.

EXPERIMENTS IN 1914

In the spring of 1914, 198 larvæ were obtained. The moths began emerging May 25. Emergence reached its height about June 15. The first larvæ were found June 5. The first pupæ were taken June 25. By July 10 the summer brood of moths was beginning to emerge. Within ten days the second-brood larvæ were at work. The first of August, third-brood pupæ were found. Moths emerged about August 15, and the third-brood larvæ were at work by August 20.

Observations in the field indicated that larvæ were hatching in large numbers almost continually from the first of June until frost.

The weather conditions for 1914 were abnormal from the first. Little rain fell thruout the season and fruit dropped badly. Orchard insects multiplied very rapidly during the extremely hot, dry weather. This was especially true of the codling moth. This season practically a full third brood of larvæ appeared.

The following diagram indicates the comparative dates of codling moth development and spraying at Lincoln.

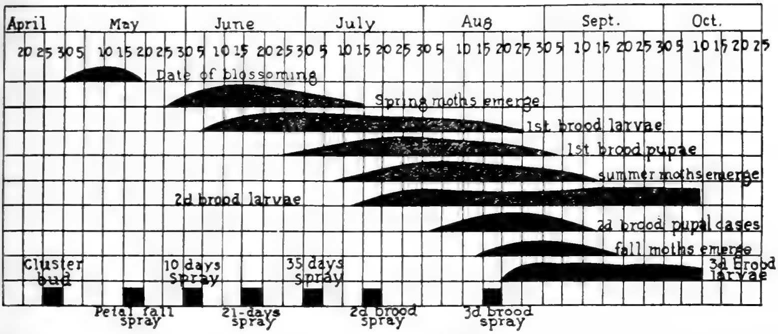


Fig. 4—Shows blooming period of apples, rate of development of codling moth, and dates when spraying was most effective for both codling moth and scab in 1914

The same general plan was followed as in 1913 except that an attempt was made to control the moths by spraying more thoroly at the petal-fall application and shifting the date of the third application.

TABLE 6—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 15 Petal-fall	May 25 10-days	June 12 25-days	June 22 35-days	July 14 2d-brood
Plat 1	Pb–2–50	Pb–2–50	....	....	Pb–2–50	Pb–2–50
2	Pb–2–50	Pb–2–50	....	Pb–2–50	....	Pb–2–50
3	Pb–2–50	Pb–2–50	Pb–2–50	....	....	Pb–2–50

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis Mo. Pippin	1	12,133	3,426	28.23
	2	14,172	3,592	25.35
	3	10,339	3,877	37.50
	check	14,845	11,024	74.26

At Beatrice (table 6), a new power sprayer of 8-gallons-to-the-minute capacity was used. Bordeaux nozzles were used for the petal-fall spray and a pressure of 225 to 250 pounds maintained. The schedule for plat 2, with an efficiency of 66 per cent, gave the best results, followed by plats 1 and 3, respectively. Over 40 per

cent of the larvæ entered at the calyx in spite of the careful spraying with Bordeaux nozzles. This was due in part to the rapid closing of the calyces during the extremely hot weather that prevailed, and in part to delay caused by an accident to the machine which made the application later than it should have been.

TABLE 7—*Lincoln spray schedule*

Date Spray	April 25 Cluster-bud	May 15 Petal-fall	June 15 25-days	June 30 35-days	July 14 2d-brood	Aug. 14 3d-brood
Plat 1	Pb–2–50	Pb–2–50	Pb–2–50	....	....	....
2	Pb–2–50	Pb–2–50	....	....	Pb–2–50	....
3	....	Pb–2–50	Pb–2–50	....	Pb–2–50	....
4	Pb–2–50	Pb–2–50	Pb–2–50	....	....	Pb–2–50
5	Pb–2–50	Pb–2–50	Pb–2–50	....	Pb–2–50	Pb–2–50
6	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis Jonathan	1	22,681	17,573	77.48
	2	21,086	14,587	69.17
	3	21,774	13,122	60.27
	4	29,688	17,035	57.38
	5	24,140	5,819	24.10
	6	19,233	3,453	17.95
	check	14,186	13,322	93.91

At Lincoln (table 7), a power machine of 10-gallons-to-the-minute capacity was used. Mist nozzles were used for the petal-fall spray and a pressure of 200 to 225 pounds was maintained. The efficiency of the spray schedule for plat 6 was 81 per cent and for plat 5, 75 per cent. The schedules for all the remaining plats were below 50 per cent, that of plat 1 being only 18 per cent.

A little more than 30 per cent of the larvæ in the fruit entered at the calyx. The fact that a high wind was blowing at the time of the petal-fall spray, making it impossible to spray except from one direction, may account for the high percentage of calyx worms. However, by far the greater percentage of injury was from worms entering the sides of the apples during August and September. That the greater part of the damage was done by late "worms" is shown by the high percentage controlled by the last three sprays.

The results of the year's work again indicate that the petal-fall spray was not thoro enough. The poor results of this spray were doubtless due to the extremely rapid reproduction of the moths which escaped poisoning at that time. Considering the number of "worms" which entered the fruit at the calyx and the number which entered the fruit thru this point on unsprayed trees, the efficiency of the calyx application was slightly above 55 per cent.

Considering the number of first-brood larvæ trapped on the sprayed and on the unsprayed trees, the efficiency of the calyx spray was much higher. The average number of moths captured under bands on sprayed trees was 12.6 and on the unsprayed trees was 151. This would make the efficiency of the calyx and the next application combined, 91.7 per cent.

There is no doubt some error in any methods of calculating the efficiency of a single spray, unless applied alone. Many of the larvæ upon entering a calyx well filled with poison, especially where it is combined with lime sulphur or Bordeaux, will no doubt be repelled by the covering and seek other points of entrance. Again the calyces of many varieties of apples, such as Grimes and Ben Davis, expand considerably as the fruit grows, which will, to some extent, diminish the protection by exposing new, unpoisoned surfaces. Hence it is likely that some "worms" which, except for the poison, would have entered the fruit at the calyx, enter some place else, while others find a safe entrance at the calyx in spite of the poison.

EXPERIMENTS IN 1915

The spring and summer of 1915 and the following fall were too cool for the coddling moth to reproduce rapidly, consequently only two broods appeared. Only 176 larvæ were collected for early observations and of these but 63 produced moths. The moths began emerging the first of June. Larvæ began appearing after June 15. No pupæ were found until about July 20. Second-brood moths began emerging from these about August 10. The second-brood larvæ commenced work about August 25. By this time in 1914 the third-brood larvæ were appearing.

1915

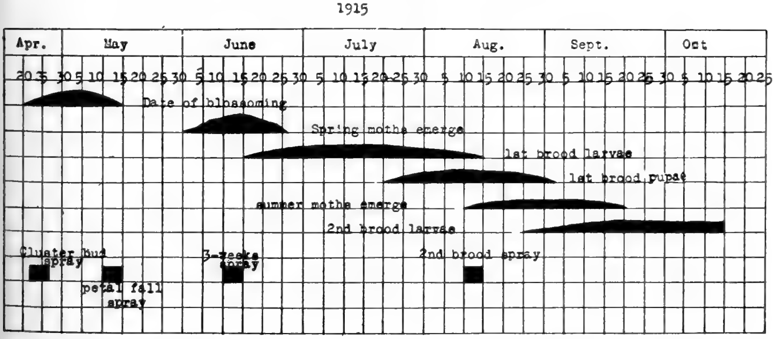


Fig. 5—Shows blooming period of apples, rate of development of codling moth, and dates when spraying was most effective for both codling moth and scab in 1915

The weather conditions during the season of 1915 were slightly abnormal in that the precipitation was more than usual and ex-

tended well into the fall. The temperature during the greater part of the season was slightly lower than normal. Because of these conditions the codling moth did not multiply as rapidly as during the two preceding seasons. The broods were more definitely defined, and the second brood was considerably later in appearing than in 1913 or 1914.

The same general plan was followed as in 1913 and 1914. A strenuous effort was made to fill all the calyx cups thoroly, and it was planned to apply the third spray on different plats 7, 14, 21, and 35 days respectively after the falling of the petals.

TABLE 8—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 24 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1...	Pb-1.5-50	Pb-1.5-50	[1]Pb-1.5-50	....	....	Pb-1.5-50
2...	Pb-1.5-50	Pb-1.5-50	....	[1]Pb-1.5-50	....	Pb-1.5-50
3...	Pb-1.5-50	Pb-1.5-50	Pb-1.5-50	....	[1]Pb-1.5-50	Pb-1.5-50
4...	Pb-1.5-50	Pb-1.5-50	Pb-1.5-50	....	Pb-1.5-50	....

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Ben Davis	1	1,602	178	11.11
	2	4,711	111	2.36
	3	1,733	48	2.77
	4	1,710	119	6.96
	check	6,853	2,224	32.45
Mo. Pippin	1	1,510	85	5.63
	2	2,631	111	4.22
	3	2,037	29	1.42
	4	914	45	4.92
	check	5,966	1,649	27.64
Ben Davis Mo. Pippin	1	3,112	263	8.45
	2	7,342	222	3.02
	3	3,770	77	2.04
	4	2,624	164	6.25
	check	12,819	3,873	30.21

At Beatrice (table 8), the same machinery was used as in 1914 Bordeaux nozzles were used for the petal-fall spray on all but on plat, and a pressure of 225 to 250 pounds was maintained. Coars mist nozzles at a pressure of 250 pounds were used on one pla The efficiency of the schedules was: No. 3, 93.3 per cent; No.

[1]Arsenate of lead was combined with Bordeaux.

90 per cent; No. 4, 80 per cent; and No. 1, 73 per cent. It is impossible to account satisfactorily for the poor results in plat No. 1, except that this plat was the south row of the orchard and being on the outside was reinfested from other sources. Less than 2 per cent of the larvæ entered the fruit at the calyx. Where coarse mist nozzles were used at the petal-fall spray, less than one per cent of calyx wormy apples were found.

TABLE 9—*Lincoln spray schedule*

Date Spray	April 26 Cluster-bud	May 10 Petal-fall	May 18 7-days	June 1 14-days	June 8 21-days	June 24 35-days	Aug. 11 2d-brood
Plat 1..	....	Pb–1.5–50	....	Pb–1.5–50	....	....	Pb–1.5–50
2..	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	....	....	....	Pb–1.5–50
3..	Pb–1.5–50	Pb–1.5–50	....	Pb–1.5–50	....	....	Pb–1.5–50
4..	Pb–1.5–50	Pb–1.5–50	....	....	Pb–1.5–50	....	Pb–1.5–50
5..	Pb–1.5–50	Pb–1.5–50	....	Pb–1.5–50	....	Pb–1.5–50	Pb–1.5–50
6..	Pb–1.5–50	Pb–1.5–50	....	Pb–1.5–50	....	....	....

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Jonathan	1	6,744	154	2.28
	2	4,919	162	3.29
	3	3,037	15	.49
	4	6,980	95	1.36
	5	4,463	60	1.34
	6	5,007	378	7.55
	check	6,410	1,184	18.47
Winesap	1	3,692	79	2.14
	2	2,582	93	3.60
	3	2,057	107	5.20
	4	1,385	64	4.62
	5	2,274	40	1.76
	6	....	....	....
	check	2,343	851	36.32
Ben Davis	1	2,057	30	1.46
	2	2,088	44	2.11
	3	2,867	24	.84
	4	1,867	14	.75
	5	2,486	42	1.69
	6	2,265	121	5.34
	check	2,880	1,715	59.55
Jonathan Winesap Ben Davis	1	12,493	263	2.105
	2	9,589	309	3.22
	3	7,961	146	1.83
	4	10,232	173	1.69
	5	9,223	142	1.54
	6[1]	7,272	499	6.86
	check	11,633	3,750	32.24

[1]No Winesap.

At Lincoln (table 9), the same machinery was used as the year before. Bordeaux nozzles were used for the petal-fall spray on all but one plat. The pressure was not as constant as it should have been, varying from 175 to 250 pounds. No tower was used, but one man sprayed from the top of the engine house on the rear of the machine. The efficiency of this schedule was: No. 5, 95 per cent; No. 4, 94.5 per cent; No. 3, 94 per cent; No. 1, 93.5 per cent; No. 2, 90 per cent; and No. 6, 79 per cent. Slightly more than 10 per cent of the larvæ entered at the calyx. Certainly the schedule would have been more efficient had the pressure been more constant, and had the principal part of the spraying been done from a tower.

TABLE 10—*South Omaha spray schedule*

Date Spray	April 27 Cluster-bud	May 11 Petal-fall	May 22 7-days	May 29 14-days	June 11 21-days	June 25 35-days	Aug. 13 2d-brood
Plat 1..	Pb-2-50	Pb-2-50	Pb-2-50	....	....	....	Pb-2-50
2..	Pb-2-50	Pb-2-50	....	Pb-2-50	....	....	Pb-2-50
3..	Pb-2-50	Pb-2-50	....	....	Pb-2-50	....	Pb-2-50
4..	Pb-2-50	Pb-2-50	....	Pb-2-50	....	Pb-2-50	Pb-2-50
5..	Pb-2-50	Pb-2-50	....	Pb-2-50	....	Pb-2-50	....

Codling moth injury on windfalls and picked fruit

Variety	Plat	Total fruit	Codling moth	Per cent
Jonathan	1	3,130	8	.256
	2	4,703	13	.276
	3	4,062	9	.222
	4	5,094	42	.824
	5	2,883	76	2.636
	check	6,353	603	9.492
	[1]	4,189	51	1.2175
Ben Davis	1	680	11	1.6177
	2	3,195	35	1.095
	3	2,482	5	.2014
	4	1,243	9	.7241
	5	1,141	36	3.155
	check	1,333	108	8.102
Jonathan Ben Davis	1	3,810	19	.499
	2	7,898	48	.607
	3	6,544	14	.214
	4	6,337	51	.805
	5	4,024	112	2.783
	check	7,686	711	9.25

[1]Given second brood spray only.

At South Omaha (table 10), a power sprayer of 10- to 12-gallons-to-the-minute capacity was used. At the petal-fall spray, coarse mist nozzles were used with a pressure of 225 to 250 pounds. Two men sprayed from the tower and one from the ground.

The efficiency of the schedule was, for plat No. 3, 97.7 per cent; No. 1, 94.7 per cent; No. 2, 93.5 per cent; No. 4, 91.3 per cent; and No. 5, 70 per cent. Approximately 3 per cent of the "worms" found in the fruit entered at the calyx end.

The low percentage of wormy fruit in the check trees was due to the fact that Mr. Beavers has been spraying thoroly for several seasons past. Two trees were selected in an orchard which has never been sprayed, one-half mile from Mr. Beavers' orchard, and the fruit examined. The Ben Davis apples were 60 per cent wormy and the Jonathan 49 per cent wormy.

TABLE 11—*Effects of various commercial arsenates of lead*

	Treatment	Applications	Total number picked apples	Codling moth	Per cent	Efficiency
	1913					
1	2–50 Herman's calcite	1–2–3–4	1,365	138	10.11	69
2	1½–50 Ansbacher powdered arsenate of lead	1–2–3–4	1,766	190	10.76	68
3	2½–50 Ansbacher powdered arsenate of lead	1–2–3–4	4,674	467	9.99	70
4	2–50 DeVoe & Reynolds paste arsenate of lead	1–2–3–4	3,741	386	10.31	69
5	2–50 Sherwin-Williams paste arsenate of lead	1–2–3–4	2,976	352	11.83	67
6	2–50 Grasselli paste arsenate of lead	1–2–3–4	5,416	676	12.46	63
7	2–50 Rex paste arsenate of lead	1–2–3–4	2,761	331	11.99	64
8	3–50 Rex paste arsenate of lead	1–2–3–4	1,896	231	12.18	63
9	2–50 Hemingway's paste arsenate of lead	1–2–3–4	1,241	143	11.52	65
10	Check	no spray	3,530	1,172	33.2	......
	1915					
1	1¼–50 Sherwin-Williams powdered arsenate of lead	1–2–3–4	12,783	381	2.12	93.5
2	1¼–50 Corona powdered arsenate of lead	1–2–3–4	6,051	187	3.09	90.5
3	2½–50 Rex paste arsenate of lead	1–2–3–4	10,774	132	1.22	96
4	Check	no spray	11,633	3,750	32.24	......

A careful perusal of table 11 indicates that 2 pounds of arsenate of lead paste or $1\frac{1}{4}$ pounds of arsenate of lead powder is sufficient. Much complaint has been registered against certain brands of arsenate of lead. The above results show them to be of about equal value, in proportion to the amount of arsenic contained in combination.

The results of the last year's work (1915) indicate that conclusions drawn from the two preceding years' work were in the main correct, i. e., that the efficiency of a spray schedule for the control of codling moth depends very largely upon the thoroness of the petal-fall application. However, this application is not in itself sufficient, even though every calyx receive a good dose of poison. Approximately 20 per cent of the first-brood "worms" normally enter the fruit at various points, other than the calyx, on unsprayed trees. The spray materials lodged in the calyces certainly will cause some of the larvæ which would otherwise enter the calyx to seek other places of entrance, so that the percentage of the larvæ which enter the fruit from other points must be appreciably increased. This is borne out by the fact that even with the most thoro calyx spraying in 1915, 20 to 40 per cent of the worms were controlled by the late applications. Comparing the number of calyx-wormy apples found on the sprayed and the unsprayed trees, the efficiency of the calyx spray was 97.7 per cent at Beatrice, 96.5 per cent at South Omaha, and 89 per cent at Lincoln.

After carefully comparing all data for the three years' work, it is apparent that in any orchard, unless very thoro spraying has been practiced in the past, it will be necessary to make three applications during a normal season and four or possibly five during an excessively hot, dry season like that of 1914. Even in well-sprayed orchards the omission of one of these sprays for a single season is inadvisable. Two or three per cent of a crop saved will pay for considerable spraying.

It is very evident that the petal-fall application is by far the most important. The best results were obtained when the spray was applied as a coarse mist (not necessarily with Bordeaux nozzles) under considerable pressure and directed squarely against the open calyx. For this reason the main part of the spraying for this application should be done from the tower. If, on account of high winds or other unfavorable conditions, the application has not been thoro, it will pay to go over the orchard again immediately.

The highest efficiency from the next spray following the calyx application was secured when it was applied just before the young

larvæ began to hatch.[1] At this time the calyces point down and the spray should be directed against the fruit and foliage from all angles to insure complete covering. Normally this spray should be applied 14 to 21 days after the petals fall.

Next to the calyx-spray the second-brood application is the most important. It should be applied just as the second-brood larvæ begin to hatch, and in the same manner as for the preceding spray.

Two pounds of lead to 50 gallons of spray was found to be as efficient as more. There is some indication that the cluster-bud spray in some of the schedules had some effect in controlling codling moth injury, but there is not enough evidence of this to warrant making any statement to that effect.

THE PLUM CURCULIO

In the past the plum curculio has not been considered as a particularly serious pest in Nebraska, except on stone fruits. However, from certain sections of the state so much damage has been reported of late years that it was deemed expedient to attempt to evolve some means of controlling the insect. Accordingly, a study was made of the effects which sprays, applied for the control of codling moth, would have on the plum curculio.

The primary injury done by the curculio consists of small holes made in the apples in feeding and for depositing eggs. However, this is only a small part of the injury. These punctures cause the fruit to become ill-shaped and knotty, and admit fungi.

The beetles pass the winter as adults under trash and rubbish, and emerge and begin feeding on the new leaves before the blossoms open. As soon as the fruit sets they begin feeding on it and depositing their eggs.

There seems to be a division of opinion among workers along this line as to whether any feeding is done by the curculio before

[1]The only way to know definitely when this and the second-brood spray should be applied is to observe the development of the moths and larvæ each season. The importance of this may be readily seen by comparing the charts for the different years and noting the different dates of hatching of the larvæ.

There is a correlation between weather conditions and the development of the codling moth. Not only are all of the periods of the life cycle of the insect shorter in midsummer when the days are long and hot than they are earlier in the spring, but they are shorter thruout and the insects develop much more rapidly during hot, dry seasons like 1914 than in cool, moist weather of seasons like 1915. Temperature seems to be the determining factor. During the time when observations were being taken, the larvæ were always found more lively on warm than on cool days. In fact on one occasion when the temperature suddenly dropped to 40 degrees the larvae remained almost entirely inactive. It was also noted that the emergence of the moths was closely correlated with the temperature. The moths would emerge in large numbers during bright, warm weather; and during a drop in temperature would cease emerging altogether, to begin again as the temperature rose.

By collecting larvæ early in the spring, keeping them confined until they pupate and emerge as moths, then repeating the operation for the second brood and the third brood, if necessary, and by noting weather conditions, every orchardist should be able to spray so that he may secure the highest efficiency from the materials used. The best materials will give at best poor results if used at the wrong time.

the blossoms open (Stedman, 1904, Crandall, 1905, and Brooks, 1910). The beetles were found at work in Nebraska before this time, and it was determined to try a poison spray applied before the regular petal-fall application.

EXPERIMENTS IN 1913

Notes on curculio injury were taken from the same trees and at the same time that the codling moth data were taken. For methods of spraying, etc., see discussion on control of codling moth. In the tables, larvæ are designated as "worms," and feeding punctures, egg punctures, etc., as "stings."

TABLE 12—*Wymore spray schedule*

Date Spray	April 21 Cluster-bud	May 5 Petal-fall	May 22 3-weeks	July 2 Second-brood
Plat 1	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio			
			Worms	Per cent	Stings	Per cent
Ben Davis	1	10,472	24	.23	51	.51
Missouri Pippin	check	2,203	13	.59	214	9.71

At Wymore the efficiency of the schedule was 63 per cent in the control of larvæ and 99.48 per cent in the control of skin punctures. This would indicate that the spray acted as a repellent in addition to poisoning the insects. The fact that the orchard was under clean cultivation would also account, in part, for the comparatively low percentage of stings.

TABLE 13—*Brownville spray schedule*

Date Spray		May 8 Petal-fall	May 31 3-weeks	
Plat 1	....	Pb–2–50	Pb–2–50	....

(1904) Stedman, J. M. The sting in the apple. Missouri Sta. Bul. No. 64.
(1905) Crandall, Chas. S. The curculio and the apple. Illinois Sta. Bul. No. 98.
(1910) Brooks, Fred E. Three snout beetles that attack apples. West Virginia Sta. Bul No. 126.

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio			
			Worms	Per cent	Stings	Per cent
Ben Davis	1	20,273	532	2.62	1,091	5.38
Missouri Pippin	check	1,804	102	5.10	119	6.59

At Brownville (table 13), the efficiency of the schedule was 54 per cent in controlling the larvæ, which was nearly as much as for the 4-spray schedule at Wymore, but in the control of skin punctures the efficiency was only 19 per cent.

TABLE 14—*Nemaha spray schedule*

Date Spray	April 23 Cluster-bud	May 7 Petal-fall	May 30 3-weeks	July 3 Second-brood
Plat 1	....	Pb-2-50	Pb-2-50	Pb-2-50
2	Pb-2-50	Pb-2-50	Pb-2-50	Pb-2-50

Curculio injury on windfalls and picked fruit

	Plat	Total fruit	Curculio	Per cent
Ben Davis	1	2,180	59	2.71
Winesap	1	2,941	74	2.52
Jonathan	1	2,751	76	2.76
	Total	7,872	209	2.65
Ben Davis	2	1,834	5	.27
Winesap	2	1,887	5	.26
Jonathan	2	2,751	8	.29
	Total	6,472	18	.28

At Nemaha (table 14), apples containing larvæ and those injured by punctures were grouped together under one head. There were few larvæ compared to punctures. No checks were left here; hence it is impossible to compute the efficiency of the schedule. However, the results indicate, provided the infestation was comparable to that at Brownville (table 13), that a large portion of the injury may be controlled by the first spray.

TABLE 15—*Florence spray schedule*

Date Spray	April 24 Cluster-bud	May 10 Petal-fall	June 3 3-weeks	July 16 Second-brood
Plat 1.......	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio	Per cent
Ben Davis Winesap Jonathan	1 check	2,154 3,285	3 285	.14 8.68

At Florence (table 15), as in table 14, both larvæ and punctures were grouped together. The efficiency for the schedule for both combined was 99.86. The results of the year's work clearly indicate that the damage caused by the plum curculio can be greatly reduced by spraying.

EXPERIMENTS IN 1914

During this season both larvæ and punctures are grouped under the same heading. The damage done by curculio this year was very light.

TABLE 16—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 15 Petal-fall	May 25 10-days	June 12 25-days	June 22 35-days	July 14 2d-brood codling moth
Plat 1...	Pb–2–50	Pb–2–50	....	....	Pb–2–50	Pb–2–50
2...	Pb–2–50	Pb–2–50	Pb–2–50	....	....	Pb–2–50
3...	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50	....	Pb–2–50
4...	....	Pb–2–50	....	Pb–2–50	....	Pb–2–50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio	Per cent
Mixed	1	8,573	3	.035
	2	9,613	0	.0
	3	11,242	0	.0
	4	7,251	119	1.64
	check	14,845	393	2.647

For schedules Nos. 1, 2, and 3 (table 16) the efficiency was practically 100 per cent. For schedule No. 4 the efficiency was 48 per cent. This difference, when considering the amount of infestation, could easily be due to individual variation.

TABLE 17—*Wymore spray schedule*

Date Spray	April 23 Cluster-bud	May 14 Petal-fall	June 10 3-weeks	July 12 Second-brood
Plat 1.......	Pb-2-50	Pb-2-50	Pb-2-50	Pb-2-50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio	Per cent
Ben Davis Mo. Pippin	1	5,603	2	.03
	check	4,063	4	.09

At Wymore (table 17), there was practically no damage by curculio either on the sprayed plats or on the checks. Probably the fact that the orchard was thoroly sprayed and cultivated the year before would account in part for the light infestation.

TABLE 18—*Seward spray schedule*

Date Spray	April 30 Cluster-bud	May 20 Petal-fall	June 18 3-weeks
Plat 1....................	Pb-2-50	Pb-2-50	Pb-2-50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio	Per cent
Ben Davis Winesap	1	4,180	9	.21
	check	1,982	41	2.07

The efficiency of the schedule at Seward (table 18) was approximately 90 per cent. Here, as in the other orchards, the infestation was so light that there was very little damage even on the check trees.

TABLE 19—*Lincoln spray schedule*

Date Spray	April 25 Cluster-bud	May 15 Petal-fall	June 15 3-weeks	July 14 Second-brood codling moth
Plat 1	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50
2	Pb–2–50	Pb–2–50	....	Pb–2–50
3	....	Pb–2–50	Pb–2–50	Pb–2–50
4	Pb–2–50	Pb–2–50	Pb–2–50	Pb–2–50

Curculio injury on windfalls and picked fruit

	Total fruit	Curculio	Per cent
Plat 1	22,681	0	.0
2	21,086	19	.09
3	21,774	348	1.64
4	23,569	0	.0
Check	14,186	361	2.54

The efficiency of schedules Nos. 1, 2 and 4 (table 19) was approximately 100 per cent and that of schedule No. 3, 37 per cent.

The curculio infestation in all of the orchards under observation was so light that no reliable conclusion can be drawn. However the importance of the cluster-bud application as shown in tables 16 and 19 must be more than a coincidence.

EXPERIMENTS IN 1915

In 1915, the work was continued as in the preceding years, but in the data the larvæ and skin punctures were recorded separately.

TABLE 20—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 24 14-days	August 10 Second-brood codling moth
Plat 1	[1]Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50
2	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	....
3	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	[1]Pb–1.5–50
4	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	....

[1]Arsenate of lead was combined with Bordeaux mixture instead of lime sulphur.

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio worms	Per cent	Curculio stings	Per cent
Ben Davis....	1	3,156	0	.0	103	3.26
	2	3,112	0	.0	132	4.21
	3	3,289	6	.18	147	4.46
	4	2,794	1	.03	92	3.26
	check	12,819	162	1.26	1,016	7.93

The results in table 20 would indicate that there is very little if any benefit derived from the second-brood spray for codling moth, so far as curculio injury is concerned.

TABLE 21—*Omaha spray schedule*

Date Spray	April 27 Cluster-bud	May 11 Petal-fall	May 22 7-days	May 29 14-days	June 11 21-days	Aug. 13 2d-brood
Plat 1......	Pb–2–50	Pb–2–50	Pb–2–50	....	....	Pb–2–50
2......	Pb–2–50	Pb–2–50	....	Pb–2–50	....	Pb–2–50
3......	....	Pb–2–50	....	Pb–2–50	....	Pb–2–50
4......	Pb–2–50	Pb–2–50	....	....	Pb–2–50	Pb–2–50

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio worms	Per cent	Curculio sting	Per cent
Jonathan.....	1	2,644	0	.0	10	.38
	2	4,651	0	.0	36	.77
	3	4,069	11	.2704	43	1.06
	4	3,912	0	.0	20	.51
	check	6,353	28	.4407	207	3.26
Ben Davis....	1	1,107	0	.0	7	.63
	2	1,875	0	.0	24	1.28
	3	2,064	8	.3876	50	2.42
	4	1,241	0	.0	8	.64
	check	1,333	39	2.92	114	8.55
Jonathan Ben Davis	1	3,751	0	.0	17	.45
	2	6,526	0	.0	60	.99
	3	6,133	19	.31	93	1.52
	4	5,153	0	.0	28	.54
	check	7,686	67	.87	321	4.18

The results shown in table 21 indicate that the regular sprays intended for the control of the codling moth, plus an earlier spray, will control practically all of the curculio larvæ and approximately

80 per cent of the damage from skin punctures. This table shows the efficiency of the first spray alone to be nearly 50 per cent. The light infestation in this orchard is due largely to the fact that clean culture is practiced and all windfalls removed.

TABLE 22—*Lincoln spray schedule*

Date Spray	April 26 Cluster-bud	May 10 Petal-fall	May 18 7-days	June 1 14-days	June 8 21-days	June 24 35-days	Aug. 11 2d-brood
Plat 1	....	Pb–1.5–50	....	Pb–1.5–50	....	....	Pb–1.5–5
2	Pb–1.5–50	Pb–1.5–50	Pb–1.5–50	....	....	....	Pb–1.5–5
3	Pb–1.5–50	Pb–1.5–50	....	Pb–1.5–50	....	....	Pb–1.5–5
4	Pb–1.5–50	Pb–1.5–50	....	....	Pb–1.5–50	....	Pb–1.5–5
5	Pb–1.5–50	Pb–1.5–50	....	....	....	Pb–1.5–50	Pb–1.5–5

Curculio injury on windfalls and picked fruit

Variety	Plat	Total fruit	Curculio worms	Per cent	Curculio sting	Per cent
Jonathan	1	6,483	147	2.27	274	4.23
	2	5,753	15	.26	111	1.93
	3	3,037	0	.0	15	.49
	4	6,980	0	.0	215	3.08
	5	4,463	2	.045	167	3.74
	check	6,410	177	2.76	917	14.30
Winesap	1	2,207	19	.86	63	2.85
	2	2,918	6	.21	102	3.49
	3	2,057	3	.15	33	1.60
	4	1,385	0	.0	52	3.75
	5	2,274	0	.0	79	3.47
	check	2,343	131	5.59	396	16.90
Ben Davis	1	1,498	18	1.20	145	9.68
	2	2,214	9	.41	41	1.85
	3	2,867	0	.0	93	3.24
	4	1,867	0	.0	38	2.03
	5	2,486	0	.0	53	2.13
	check	2,880	122	4.24	433	15.03
Jonathan Winesap Ben Davis	1	10,188	184	1.81	482	4.73
	2	10,885	30	.27	254	2.33
	3	7,961	3	.038	141	1.77
	4	10,232	0	.0	305	2.98
	5	9,223	2	.022	299	3.24
	check	11,633	430	3.70	1,746	15.01

The evidence presented in table 22 corroborates the statements made in regard to table 21. However, as compared with table 21 it shows a lower general efficiency. This is no doubt due to the

fact that the orchard was allowed to grow up to grass and weeds, and that windfall apples were allowed to remain under the trees. In the early windfalls, many curculio larvæ lived to maturity and thus reinfested the orchard.

Considering all the facts known in regard to the life history of the plum curculio and the facts gathered during the last three years' work, the accumulated evidence shows that by taking advantage of certain habits of the insect, its control is comparatively easy and certain.

(1) The adults hibernate during the winter under trash and rubbish in the orchard.

(2) After a winter of fasting they are very voracious and in the spring commence feeding on the new leaves and buds before the blossoms are open.

(3) The larvæ are unable to live to maturity in the apples when they remain on the tree. Only those larvæ which are in the apples that fall early reach maturity and become beetles.

(4) The larvæ begin entering the ground about the middle of July and continue up to the middle of August or later. The pupæ cases are placed at an average depth of 1 to 2 inches.

Therefore, control measures which suggested themselves and which proved effective are: The removal of trash and rubbish, accompanied by early spring plowing; thoro spraying with arsenate of lead before the blossoms open, followed by the regular codling moth schedule; the removal of early windfalls, which may contain larvæ, from the orchard; and lastly, thoro cultivation of the orchard from the middle of July to the middle of August.

SPRAYING FOR THE CONTROL OF FUNGOUS DISEASES

APPLE SCAB

One of the determining factors in the production of apples in Nebraska is the prevalence of apple scab. This disease has long been considered serious and a great deal of work has been done concerning its life history and methods of control. Notwithstanding the fact that its destructiveness is well known and that reasonably sure methods of control have been published, the disease goes merrily on taking its toll of more than 50 per cent of the fruit of the state. As a matter of fact the loss is often even more than it appears. 1. The young apples drop prematurely, due to the attacks of the fungus upon the flowers and petioles before and during the blossoming period, and on the young fruit later. This was especially noticeable during the seasons of 1913 and 1915. At blossoming time the bloom was as heavy on the check as on the sprayed trees. The set of fruit on the sprayed trees was

much heavier than on the check trees, and the number of apples which dropped prematurely much less. This was also noted by Emerson (1905). 2. The leaves are also attacked. In unsprayed orchards, the foliage is sometimes so severely injured that the fruit never attains salable size, and scarcely any growth is made by the trees. It often takes two or three years of thoro spraying to bring the trees back to normal growth and productiveness. 3. Scab also impairs the keeping qualities of fruit. At harvest time in 1915 several boxes of Winesap, Arkansas, and Ben Davis apples were sorted for exhibition, and for use in fruit judging. A part of each variety came from trees having considerable scabby fruit and a part from trees having no scab. All the fruit was free from visible scab when packed. Some of the fruit was placed in cold storage and some in cellar storage. When the fruit was examined in January, 1916, 10 per cent of the fruit in cold storage was scabby and 68 per cent of the fruit in cellar storage was scabby. The fruit in cold storage was held a few days before being stored and was taken out 2 days before being examined.

Development of scab in storage was also reported from various growers in the State. Several of these reports were followed up, and the fruit was examined and found to have a high percentage of scab. In each case the growers stated that all scab was culled out at packing time. Scab in storage was also noted by Brooks (1908), Morse (1910), Morse and Lewis (1911), Wallace (1913), and Morris (1914).

There is no longer any doubt that the entrance of several serious soft rot fungi is facilitated by scab. Craig and Van Hook (1902), Eustace (1902).

Because of the continued loss by the growers, due to scab, notwithstanding the more or less thoro spraying, further investigation was decided upon to determine to what causes or conditions the lack of control was due.

The general appearance of this disease is so well known that space will not be taken to discuss it here.

(1905) Emerson, R. A. Apple Scab and Cedar Rust, Nebraska Exp. Sta. Bul. 88:3.

(1908) Brooks, Chas. Notes on Apple Diseases. New Hampshire Agr. Exp. Sta. Rpt. 19-20:372.

(1910) Morse, W. J. Notes on Plant Diseases 1908. Maine Agr. Exp. Sta. Bul. 164:4.

(1911) Morse, W. J. and Lewis, C. E. Maine Apple Diseases. Maine Agr. Exp. Sta. Bul. 185:352-355, 390.

(1913) Wallace, Errett. Scab Disease of Apples. Cornell Univ. Agr. Exp. Sta. Bul. 335: 574-576.

(1914) Morris, H. E. A Contribution to Our Knowledge of Apple Scab. Montana Agr. Exp. Sta. Bul. 96:75.

(1902) Craig, John and Van Hook, J. M. Pink rot, an attendant of apple scab. New York, Cornell Sta. Bul. 207.

(1902) Eustace, H. J. A destructive apple rot following scab. New York (Geneva) Sta. Bul. 227. Hypcoknus sp. another apple rot following scab. New York (Geneva) Sta. Bul. 255.

Fig. 6 shows the effect of scab on the leaves. Figs. 7 and 8 show the effect on the fruit.

Fig 6—Shows a leaf affected with apple scab and one free from scab

Fig. 7—A light infection of scab on the fruit

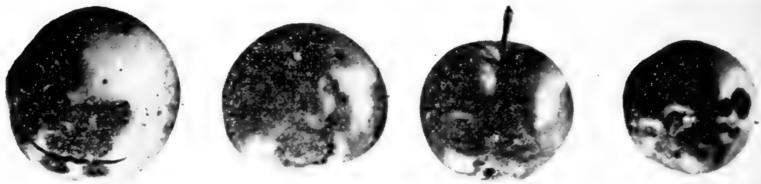


Fig. 8—A severe infection of scab on the fruit

TIME OF INFECTION

Apple scab is a cool weather disease and thrives best under conditions that allow shade and moisture. Under ordinary conditions the period of greatest infection is from the time the leaf buds begin to unfold until two or three weeks after the petals fall. That infection occurs before the blossoms open is shown by the fact that scab was found on a large number of leaves which had been enclosed in Manila paper bags before the blossoms were out. No record of the percentage of infection was secured, because the scab was not noticed until the bags were being exchanged for mosquito netting and by this time many of the clusters had been discarded. Wallace (1913) says "the first infection usually occurs when the blossoms are about to open or as soon thereafter as favorable weather conditions arise."

Where there is an abundance of dead leaves under the trees, the period of infection may be prolonged by the continued development of perithecia in the leaves during a continued period of wet weather.

Regarding the secondary or conidial infection, Wallace says:

"The period of incubation may vary from eight to fifteen days; so that after this length of time has elapsed subsequent to the date of the earliest ascospore infection a crop of conidia is produced from which a second, and usually more abundant, infection may appear eight to fifteen days following the first period of weather favorable to infection that occurs after the above crop of spores has ripened. This generation may in turn produce another, and so on throughout the season. However, the various infections do not always occur only in successive jumps at intervals of eight to fifteen days, as the above discussion might lead one to believe. The crop of ascospores are not all matured and do not all discharge at one time. They begin to ripen at about the time indicated above and furnish a constant source of infection for a month or more. Thus the individual infections belonging to the first

generation may be started at several different dates and consequently produce their first crops of conidia at different dates. It is possible also that individual infections occurring at the same time do not all have the same period of incubation. Thus there may be a more or less constant appearance of scab, with the more pronounced jumps at intervals as indicated above. In fact this is what usually occurs.

"The earliest infections usually occur on the lower side of the leaves. This is due to the fact that the lower side is more exposed at that time, while the leaves are unfolding. The later infections occur more abundantly on the upper surfaces, which by that time have assumed a more exposed position."

During the cool, damp season of 1915 there was a great deal of loss due to secondary infection occurring from the latter part of July to the middle of August. To this late infection is attributed a large part of the loss in storage due to scab injury. It is quite possible that infection was taking place later than the middle of August. In fact the evidence indicates that infection was taking place just before the fruit was harvested, and that the storage scab resulted from this late infection, or, that it was caused, after harvesting, by infection from spores on the fruit at that time. The writer is of the opinion that infection occurred before picking, from the fact that some fruit heavily scabbed was stored in the same packages with clean fruit from an orchard free from scab, and when later removed for use, no scab appeared on the fruit from the clean orchard, altho the fruit was stored in the same cellar where so much infection was found.

EXPERIMENTS IN 1913

After reviewing the work already done on the control of apple scab, and carefully going over the situation in Nebraska, it was determined to use fungicides in connection with the regular codling moth and curculio sprays but to leave them out of some of the sprays on certain plats.

Careful observations were made of the time and amount of infection. Records were kept of all scab injury, however small, and of the amount of spray injury for each schedule. No uniform time of infection was found in the different orchards. Florence was the only place where rainfall was normally abundant early in the spring, and at this place the primary infection was heavy. The secondary infection was not heavy any place in the State.

TABLE 23—*Nemaha spray schedule*

Date Spray	April 23 Cluster-bud	May 7 Petal-fall	May 30 3-weeks	July 13 2d-brood	July 25
Plat 1......	Bx-3-4-50	LS-1.5-50	LS-1.5-50	Bx-3-4-50	....
2......	Bx-3-4-50	LS-1.5-50	LS-1.5-50	LS-1-50	Bx-3-4-50
3......	LS-1.5-50	LS-1.5-50	LS-1.5-50	LS-1-50	....
4......	LS-1.5-50	LS-1.5-50	LS-1.5-50	LS-1-50	LS-1-50

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent	Spray injury	Per cent
Ben Davis..........	1	2,180	22	1.01	169	7.752
	2	1,834	10	.54	439	23.93
	3	7,691	46	.60	123	1.60
	4	8,370	95	1.13	335	4.00
Winesap..........	1	2,941	61	2.07	200	6.80
	2	1,887	60	3.18	448	25.86
	3	15,258	373	2.44	446	2.92
	4	16,714	254	1.52	690	4.13
Jonathan..........	1	2,751	32	1.16	254	9.23
	2	2,751	15	.54	259	9.42
	3	11,513	79	.69	187	1.62
	4	12,555	140	1.11	486	3.87
Combined varieties.	1	7,872	115	1.46	623	7.91
	2	6,472	85	1.31	1,146	17.71
	3	34,462	498	1.44	756	2.19
	4	37,639	489	1.30	1,511	4.01

At Nemaha (table 23), no check was left. Therefore, the data are of little value except as a comparison of the value of Bordeaux and lime sulphur, and to show the value of a late spray. The results here indicate that there is practically no difference between the effectiveness of Bordeaux and lime sulphur as a fungicide for scab. They also show that no benefit was derived from the spray following the second-brood codling moth application. However, the summer had been so dry that little effect could be expected. Bordeaux caused more injury at the second-brood application than did lime sulphur and considerably more at the later application. This later application was followed immediately by rainy weather, which may account for the Bordeaux injury. This orchard was neither cultivated nor sprayed before this season.

TABLE 24—*Brownville spray schedule*

Date / Spray	Cluster-bud	May 5 Petal-fall	May 30 3-weeks
Plat 1	....	LS-1.5-50	LS-1.5-50
2	....	LS-1.5-50	Bx-3-4-50
3	....	LS-1.5-50	LS-1.5-50
4	....	Bx-3-4-50	Bx-3-4-50

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent	Spray injury	Per cent
Ben Davis and Missouri Pippin in equal number, except in plat 3 which consists of Arkansas exclusively.	1	4,790	53	1.11	49	1.02
	2	4,638	37	.80	15	.32
	3	2,538	17	.67	809	31.87
	4	5,071	58	1.14	2,132	42.04
	check	1,804	312	17.29	....	....

At Brownville (table 24), the petal-fall spray, together with the spray following, proved 93.5 per cent efficient on the control of scab where lime sulphur was used for both applications. Where Bordeaux was used for the second spray (plat 2) the efficiency was 95.4 per cent. Where Bordeaux was used for both applications (plat 4) the efficiency showed slightly less than in the case of either plat 1 or 2. The spray injury on this plat was so severe as to bar Bordeaux from use as a fungicide for the petal-fall spray. Plat 3 consisted of the variety Arkansas, alone. On this plat two applications proved to have a slightly higher efficiency in controlling scab than in any of the other plats, but here again the spray injury was very severe. The weather during and following the second application was very hot and dry and the burning was no doubt due to the rapid oxidation of some of the sulphur compounds in the spray. The variety Arkansas seemed to be especially susceptible to this injury. The foliage of all the plats where lime sulphur was used for the second application showed considerable burning, while the foliage on the Bordeaux plats was dark green and free from injury. The foliage was not injured on plat 4. This orchard had never been cultivated or sprayed.

TABLE 25—*Florence spray schedule*

Date Spray	April 24 Cluster-bud	May 10 Petal-fall	June 3 3-weeks	July 16 Second-brood
Plat 1	Bx-3-4-50	Bx-3-4-50	Bx-3-4-50	Bx-3-4-50
2	Bx-3-4-50	LS-1.5-50	Bx-3-4-50	Bx-3-4-50
3	Bx-3-4-50	LS-1.5-50	LS-1.5-50	Bx-3-4-50
4	Bx-3-4-50	LS-1.5-50	LS-1.5-50	LS-1.5-50
5	LS-1.5-50	LS-1.5-50	LS-1.5-50	LS-1.5-50
6	....	LS-1.5-50	LS-1.5-50	LS-1.5-50
7	LS-1.5-50	....	LS-1.5-50	LS-1.5-50
8	LS-1.5-50	LS-1.5-50	....	LS-1.5-50
9	LS-1.5-50	LS-1.5-50	LS-1.5-50	....
10	Bx-3-4-50	Bx-3-4-50	Bx-3-4-50	Bx-3-4-50
11	LS-1.5-50	LS-1.5-50	LS-1.5-50	LS-1.5-50

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Ben Davis Winesap Northwest Greening	1	2,295	24	1.04	674	29.37
	2	1,945	37	1.90	373	19.18
	3	2,281	39	1.71	376	16.48
	4	1,598	16	1.00	144	9.01
	5	2,154	70	3.25	172	7.99
	6	1,541	181	11.74	111	7.20
	7	1,597	229	14.34	116	7.26
	8	2,265	138	6.09	210	9.27
	9	2,490	224	9.00	106	4.26
	10	3,252	1	.03	928	28.54
	11	1,495	26	1.74	129	8.63
	check	3,285	808	24.60	....	....

The highest efficiency (96 per cent) secured at Florence (table 25) was in plat 5, where Bordeaux was used for the first spray and lime sulphur for the three subsequent sprays. Bordeaux used for the first spray gave consistently better results than lime sulphur. For the subsequent sprays, however, Bordeaux shows no added advantage. An idea of the approximate value of each application was secured by omitting one spray for each of the plats. The evidence secured in this way indicates that, at this place, the first spray controlled more than 32 per cent of the total infection. The petal-fall spray controlled 28 per cent, the 3-weeks spray controlled 16 per cent, and the July spray controlled 24 per cent. These figures are only approximately correct, since it is impossible to determine how long a single application will be effective, but the results certainly show the relative value of the different applications for the one season.

The results here also indicate that, everything else being equal, the earlier in the season Bordeaux is used after the trees come into full bloom, the greater will be the danger of injury from spray burn.

TABLE 26—*Lincoln spray schedule*

Date Spray	April 25 Cluster-bud	May 9 Petal-fall	June 2 3-weeks	July 15 Second-brood
Plat 1	Bx–4–6–50	LS–1.5–50	LS–1.5–50	Bx–3–4–50
2	Bx–4–6–50	Bx–3–4–50	Bx–3–4–50	Bx–3–4–50
3	LS–1.5–50	LS–1.5–50	LS–1.5–50	LS–1.5–50

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Ben Davis Jonathan	1	2,549	2	.07	498	19.54
	2	1,884	0	.0	580	30.78
	3	1,428	15	1.05	125	8.75
	check	3,530	1,230	34.85	......	......

At Lincoln (table 26), the schedules for plats 1 and 2 gave approximately 100 per cent control. The complete lime sulphur schedule was 97 per cent efficient. Here again Bordeaux did considerable injury even where used only in July, but was especially injurious where used for the 3-weeks spray. The rainfall was certainly not more than normal at Lincoln in 1913, nor did it come at the most inopportune times, hence the weather cannot be largely to blame for the spray injury. These plats had been sprayed before but not cultivated. Lime sulphur injury was greater on the foliage than on the fruit.

The results of the year's work indicate that a pre-petal-fall spray is often very necessary, depending upon weather conditions. Bordeaux seems to be more effective as a fungicide than lime sulphur, but when used for the petal-fall spray or soon after that time it russets the fruit so badly that its use is inadvisable. However, for the first application it proved more desirable than lime sulphur.

EXPERIMENTS IN 1914

The same general plan of spraying was followed as in 1913 except that the dates of some of the sprays were shifted to correspond to the maturing and dissemination of the spores of the scab fungus.

The infection this year was very light, being comparatively negligible even on the check trees, in the orchards which were sprayed in 1913. In the orchards which had not been sprayed before, infection did not appear to a very noticeable extent until after the 10-days' spray had been applied. This season was exceptionally dry, and comparatively little secondary infection occurred.

TABLE 27—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 15 Petal-fall	May 25 10-days	June 12 25-days	June 22 35-days	July 14 2d-brood
Plat 1	Bx-4-6-50	LS-1.008	......	......	LS-1.008	LS-1.008
2	Bx-4-6-50	LS-1.008	......	LS-1.008	......	LS-1.008
3	Bx-4-6-50	LS-1.008	LS-1.008	......	......	LS-1.008
4	Bx-4-6-50	LS-1.008	......	......	Bx-3-4-50	LS-1.008
5	Bx-4-6-50	LS-1.008	......	Bx-3-4-50	......	LS-1.008
6	Bx-4-6-50	LS-1.008	Bx-3-4-50	......	......	LS-1.008

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Ben Davis	1	772	8	1.04	27	3.50
	2	3,248	32	.98	96	2.96
	3	3,485	12	.34	173	4.96
	4	5,342	16	.30	362	6.78
	5	6,074	15	.25	449	7.39
	6	2,198	16	.73	86	3.91
	check	4,377	464	10.60	......	......
Missouri Pippin	1	7,801	66	.85	90	1.15
	2	7,994	43	.54	191	2.39
	3	6,128	20	.33	98	1.60
	4	6,791	28	.41	66	.97
	5	8,098	12	.15	143	1.77
	6	8,141	10	.12	209	2.57
	check	10,468	1,307	12.49	......	......
Ben Davis Missouri Pippin	1	8,573	74	.86	117	1.36
	2	11,242	75	.67	287	2.55
	3	9,613	32	.33	271	2.82
	4	12,133	44	.36	428	3.53
	5	14,172	27	.19	592	4.18
	6	10,339	26	.25	295	2.85
	check	14,845	1,771	1.19	......	......

At Beatrice (table 27), the highest efficiency was 98.4 per cent. There was practically no difference in any of the sprayed plats.

Neither was there any appreciable difference in the amount of spray injury caused by the late sprays of either Bordeaux or lime sulphur. Practically all the infection which occurred here must have taken place about the time of the petal-fall spray as it began to be noticeable on the check trees soon after the 10-days spray.

TABLE 28—*Seward spray schedule*

Date Spray	April 30 Cluster-bud	May 20 Petal-fall	June 18 3-weeks	July 20 Second-brood
Plat 1	Bx–4–6–50	LS–1.008	LS–1.008	Bx–3–4–50
2	LS–1.009	LS–1.008	LS–1.008	LS–1.008

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Ben Davis Winesap	1	5,278	128	2.42	85	1.61
	2	4,180	83	1.99	86	2.06
	check	1,982	485	24.47	....	....

At Seward (table 28), the same conditions prevailed as at Beatrice. Here Bordeaux for the first spray showed a slightly higher efficiency than lime sulphur.

The results of the year bear out those of 1913 in regard to the comparative efficiency of Bordeaux and lime sulphur. Bordeaux this year did little injury at any of the late sprayings, due to the excessively dry weather.

In most instances, the petal-fall was the earliest spray that was necessary this year.

EXPERIMENTS IN 1915

Since no conclusive results were obtained in 1914, owing to weather conditions, the same plans were followed in 1915. This season was very favorable to the development of scab and there was a great deal of primary as well as secondary infection. As in 1913, considerable infection occurred before the trees were in bloom. Quite a heavy secondary infection occurred from the latter part of July to the middle of August or perhaps considerably later. This secondary infection was heaviest near the check trees and in the vicinity of unsprayed orchards. In some cases more than 30 per cent of the fruit on well-sprayed trees in the vicinity of check trees was infected with small scab spots at packing time regardless of the fact that scarcely any of the windfalls from these

same trees were scabby and no scab was noted on the previous examinations of the tree.

TABLE 29—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 24 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1	Bx–4–4–50	LS–1.009	LS–1.009	....	....	....
2	LS–1.01	LS–1.009	LS–1.009	....	....	....
3	LS–1.01	LS–1.009	Bx–4–4–50	....	....	....
4	LS–1.01	LS–1.009	Bx–4–4–50	Bx–4–4–50	....	....
5	LS–1.01	LS–1.009	Bx–4–4–50	....	Bx–4–4–50	....
6	LS–1.01	LS–1.009	Bx–4–4–50	....	....	Bx–4–4–50
7	LS–1.01	LS–1.009	Bx–4–4–50	....	....	LS–1.008

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Ben Davis	1	1,427	166	11.63	207	14.51
	2	1,784	242	13.56	90	5.04
	3	1,353	135	10.00	242	17.88
	4	1,848	344	18.62	119	6.44
	5	1,853	186	10.05	86	4.64
	6	1,727	0	.00	58	3.36
	7	878	12	1.37	34	3.87
	check	6,853	5,826	85.01	....	....
Missouri Pippin	1	1,729	155	8.96	9	.52
	2	1,351	53	3.92	79	5.85
	3	665	38	5.71	61	9.17
	4	3,069	235	7.66	328	10.69
	5	....	....	....	....	....
	6	1,067	3	.28	48	4.50
	7	....	....	....	....	....
	check	5,966	4,457	74.70	....	....
Ben Davis Missouri Pippin	1	3,156	321	10.17	216	6.84
	2	3,135	85	2.71	169	5.39
	3	2,018	38	1.88	303	15.01
	4	4,917	579	11.77	447	9.09
	5[1]	1,853	186	10.05	86	4.64
	6	2,794	3	.11	106	3.79
	7[1]	878	12	1.37	34	3.87
	check	12,819	10,283	80.23	....	....

At Beatrice (table 29), the most efficient schedule was that of plat 6, which was practically 100 per cent, closely followed by plat 7, which was 98.3 per cent efficient. The schedules for the

[1]No Missouri Pippin.

plats which did not receive the July spray ranged from 85.5 per cent to 89 per cent efficiency. The evidence indicates that there was quite a severe secondary infection of scab toward the latter part of the season, which was controlled on the sprayed plats by the July application.

TABLE 30—*Omaha spray schedule*

Date Spray	April 27 Cluster-bud	May 11 Petal-fall	May 22 7-days	May 29 14-days	June 11 21-days	June 25 35-days	Aug. 13 2d-brood
Plat 1	LS–1.01	LS–1.009	LS–1.009	....	....	....	....
2	LS–1.01	....	LS–1.009	....	....	....	....
3	LS–1.01	LS–1.009	....	LS–1.009	....	....	....
4	....	LS–1.009	....	LS–1.009	....	....	....
5	LS–1.01	LS–1.009	....	....	LS–1.009	....	....
6	LS–1.01	LS–1.009	....	LS–1.009	....	LS–1.009	....
7	LS–1.01	LS–1.009	....	LS–1.009	....	LS–1.009	LS–1.008

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Jonathan	1	3,770	9	.24	863	22.89
	2	2,994	0	.0	227	7.58
	3	3,961	0	.0	142	3.58
	4	4,069	0	.0	254	6.24
	5	3,278	0	.0	294	8.97
	6	2,883	0	.0	195	6.76
	7	5,094	0	.0	409	8.03
	check	6,353	296	4.66	....	....
Ben Davis	1	994	12	1.20	222	22.33
	2	1,418	13	.92	68	4.79
	3	1,875	16	.85	163	8.69
	4	2,064	9	.44	159	7.70
	5	....	....	....	....	....
	6	1,141	0	.0	88	7.71
	7	1,243	0	.0	113	9.09
	check	1,333	377	28.28	....	....
Jonathan Ben Davis	1	4,764	21	.44	1,085	22.77
	2	4,412	13	.29	295	6.69
	3	5,836	16	.27	305	5.23
	4	6,133	9	.15	413	6.73
	5[1]	3,278	0	.0	294	8.97
	6	4,024	0	.0	283	7.03
	7	6,337	0	.0	522	8.24
	check	7,686	673	8.76	....	....

[1]No Ben Davis.

At Omaha (table 30), the schedules for plats 5, 6, and 7 were 100 per cent efficient, with very little difference for the schedules of the other plats. The difference in amount of infection on some of these plats and on the check might be astonishing were it not known that the check plat was a row near a fence which could not be cultivated, while all of the sprayed plats had received clean cultivation for several years. Unless the slight difference in the efficiency of the different schedules be attributed to the natural variation to be expected or to experimental error, the evidence indicates early infection.

The spray injury is quite uniform for the different schedules except that of plat 1. The high percentage of spray injury recorded here cannot be accounted for.

At Lincoln (table 31), the evidence corroborates that of table 29 at Beatrice. The late secondary infection on the sprayed trees was heavier here than at Beatrice, tho the infection on the check trees was much lighter. This difference may be due in part to the fact that unsprayed orchards were on all sides of the plats used in the experiment, but is due in part, no doubt, to more efficient spraying at Beatrice.

The omission of a different application in each of several schedules furnishes evidence of when much of the infection occurred. It certainly proved disastrous, here, to omit the cluster-bud spray or the fungicide at the petal-fall spray as is often advocated. The control shown by the 14-days and the 21-days applications indicates that considerable infection was also occurring at this time.

TABLE 31—*Lincoln spray schedule*

Date Spray	April 26 Cluster-bud	May 10 Petal-fall	May 18 7-days	June 1 14-days	June 8 21-days	June 24 35-days	Aug. 11 12-weeks
Plat 1	....	LS–1.009	....	LS–1.009	....	....	....
2	LS–1.01	LS–1.009	....	LS–1.009	....	....	....
3	LS–1.01	LS–1.009	LS–1.009	....	....	....	....
4	LS–1.01	....	LS–1.009	....	....	....	....
5	LS–1.01	LS–1.009	....	....	LS–1.009	....	....
6	LS–1.01	LS–1.009	....	LS–1.009	....	LS–1.009	....
7	LS–1.01	LS–1.009	....	LS–1.009	....	....	LS–1.009

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Jonathan	1	6,483	1,312	20.24	278	4.29
	2	5,840	858	14.69	175	3.00
	3	4,919	826	16.87	272	5.53
	4	5,930	1,185	19.98	409	6.90
	5	6,980	932	13.35	251	3.65
	6	4,930	824	16.71	268	5.44
	7	3,037	33	1.09	253	8.33
	check	6,410	2,123	33.12	....	....
Winesap	1	2,207	625	28.34	0	.0
	2	2,501	325	13.00	0	.0
	3	2,582	541	20.95	12	.46
	4	3,015	459	15.22	49	1.62
	5	1,385	173	12.49	4	.03
	6	....	....	....	....	....
	7	2,867	88	3.07	13	.45
	check	2,343	2,009	85.75	....	....
Ben Davis	1	1,498	355	23.70	0	.0
	2	1,806	216	12.00	0	.0
	3	2,088	1,260	60.35	35	1.68
	4	1,714	556	32.44	15	.88
	5	1,867	209	11.19	27	1.45
	6	2,225	217	9.75	16	.72
	7	2,057	77	3.74	132	6.42
	check	....	....	....	....	....
Combined varieties	1	10,188	2,292	22.50	278	2.73
	2	10,147	1,399	13.78	175	1.72
	3	9,589	2,627	27.39	319	3.33
	4	10,659	2,200	20.63	473	4.44
	5	10,232	1,314	12.84	282	2.76
	6	7,155	1,041	14.54	284	3.97
	7	7,961	198	2.49	398	5.00
	check	11,633	6,188	53.19	....	....

TABLE 32—*Lincoln spray schedule*

Date Spray	April 26 Cluster-bud	May 10 Petal-fall	May 18 7-days	June 1 14-days	June 8 21-days	June 24 35-days	Aug. 11 12-weeks
Plat 1	....	LS–1.009	....	LS–1.009	....	....	LS–1.009
2	LS–1.01	LS–1.009	....	LS–1.009	....	....	LS–1.009
3	LS–1.01	LS–1.009	LS–1.009	....	....	....	LS–1.009
4	LS–1.01	....	LS–1.009	....	....	....	LS–1.009
5	LS–1.01	LS–1.009	....	....	LS–1.009	....	LS–1.009
6	LS–1.01	LS–1.009	....	LS–1.009	....	LS–1.009	LS–1.009

Scab injury on windfalls and picked fruit

Variety	Plat	Total fruit	Scab	Per cent scab	Spray injury	Per cent spray injury
Jonathan	1	6,744	357	5.29	238	3.53
	2	3,037	33	1.09	253	8.33
	3	5,753	349	6.06	82	1.43
	4	4,976	429	8.62	178	3.58
	5	5,068	43	.85	299	5.90
	6	4,463	59	1.32	250	5.60
	check	6,410	2,123	33.12	....	....
Winesap	1	3,692	579	15.68	0	.0
	2	2,867	88	3.07	13	.45
	3	2,918	236	8.06	60	2.06
	4	2,731	485	17.76	46	1.68
	5	2,274	38	1.67	3	.13
	6	....	....	....	....	....
	check	2,343	2,009	85.74	....	....
Ben Davis	1	2,057	226	1.09	42	2.04
	2	2,057	77	3.74	132	6.42
	3	2,214	111	5.01	18	.81
	4	2,221	230	10.35	7	.32
	5	1,953	89	4.56	52	2.66
	6	2,486	184	7.40	22	.88
	check	2,880	2,056	71.39	....	....
Jonathan Winesap Ben Davis	1	12,493	1,162	9.30	280	2.24
	2	7,961	198	2.49	398	5.00
	3	10,885	696	6.39	160	1.47
	4	9,928	1,144	11.52	231	2.33
	5	9,295	170	1.83	354	3.81
	6[1]	6,949	243	3.50	272	3.91
	check	11,633	6,188	53.19	....	....

Table 32 gives further evidence of a primary infection which occurred during a period of several days, beginning soon after

[1]Only Jonathan and Ben Davis.

the flower buds began to show pink and lasting until after the petals had fallen. Evidently there was also considerable infection during the period between the 14-days and the 21-days spray. The fact that all the plats in table 32 are consistent in showing less scab infection than the corresponding plats shown in table 31 is conclusive evidence of a late secondary infection which occurred at such time that the August spray controlled it to a great extent.

INCIDENTAL OBSERVATIONS

During the past three seasons a number of observations were made which were not scheduled in the regular plans.

In securing the records, it was noted that there was considerable consistent variation in the amount of infection on different varieties of apples. This led to a study of all the available varieties, to determine which, if any, were resistant to scab. After three seasons of this work, it was found that the records of a variety for one season did not always correspond with the records of the same variety for another season; e. g., the variety Winesap is usually considered much more susceptible than Ben Davis. The records bear this out for 1913 and 1914, but in 1915 scab was, in many instances, more prevalent on Ben Davis apples than on Winesap. On the average perhaps this is not true. It was also found that none of the common varieties are entirely free from scab, altho many varieties exhibit a great deal of resistance. On comparing observations made with the results previously reported by other workers, this variation in susceptibility is emphasized. Wallace (1913) makes a similar statement and quotes extracts from other publications.

From the observations made in various orchards in the State and in the variety orchard at the Experiment Station the varieties have been tentatively grouped as follows:

Practically resistant	*Moderately resistant*	*Susceptible*
Wagner	Jonathan	Arkansas (Mammoth Blacktwig)
Oldenburg (Duchess)	York (Imperial)	Ralls (Jenet)
Wealthy	Ben Davis	Northern Spy
Patten Greening	Windsor	Red June
	Gano	Virginia Beauty
	Grimes (Golden)	Yellow Transparent
	Missouri (Pippin)	Sheriff
	Salome	Maiden Blush
	Champion	Walbridge
	Minkler	

(1913) Wallace, Errett. Scab disease of apples. Illinois Sta. Bul. 335:579-582.

Practically resistant	*Moderately resistant*	*Susceptible*
	Northwest Greening	Early Harvest
	Rome Beauty	Fameuse (Snow)
	Delicious	King David
	Red Astrachan	Chenango
	Wolf River	Paragon
	Malinda	
	Willow Twig	
	Stayman Winesap	
	Chicago	
	Utter (Red)	

Scab was always found to be more prevalent where no cultivation was practiced and decidedly less in evidence where thoro, early and late cultivation was practiced as in the case of the Beavers orchard at Omaha.

Well pruned and spaced trees were as a rule less scabby than trees which carried a dense foliage or which were so close together that the branches interlocked. This should be expected, since the more dense the foliage the longer the tree will remain moist and afford the best conditions for the germination of spores.

It was noticed that trees situated on high, rolling land were usually not so badly infected as trees on lower ground. This is due in part to the better circulation of air on the rolling land and in part to the dense foliage found on trees growing in low places, especially where proper pruning is not given.

SUMMARY

The foregoing records and observations lead to some more or less general conclusions.

Sanitation, i.e., the removal of old leaves, windfalls, and mummied apples, together with clean culture, will go a long way towards controlling the primary infection.

The proper spacing of the trees in an orchard, together with good air drainage and the right amount of pruning, will lessen the infection to some extent. However, even with an ideal orchard and the best methods of sanitation, clean fruit cannot be grown in Nebraska unless the orchards are properly sprayed.

The evidence presented shows that spraying will control the disease if applied at the proper time and that this time depends upon the time of infection. The spray must be applied before the infection in order to prevent injury. Therefore, since it has been proved that there is always more or less infection at or just before the time the blossoms are out if the weather conditions are favorable, it follows that spraying for scab must be done before

this time. .What is known as the cluster-bud stage, just as the flowers of the clusters are separating and showing "pink" but before the individual blossoms open, is the proper time for this application, according to results obtained. In dry seasons or in orchards where thoro spraying and orchard sanitation have been the rule, this application may be omitted without serious loss as shown by the results obtained in most of the orchards in 1914 and in the Omaha orchard (table 30) in 1915.

A second application at the petal-fall stage, and another two to three weeks later, are as a rule required to insure protection. During this time new surfaces of fruit and foliage are being rapidly exposed and are liable to infection. Another spray in the latter part of July or the first part of August may be necessary to prevent late infection in wet seasons such as that of 1915.

In order to secure the best results, it is necessary that the grower watch the weather conditions carefully and regulate his schedule accordingly. Thousands of bushels of apples have been lost in this State because the grower delayed spraying on account of rainy weather, fearing the spray would wash off. This is just the time when protection is needed to prevent infection. There is rarely a season in Nebraska when, because of wet weather, there is not sufficient time to spray, and if it is possible to work for only a part of a day at a time, spraying should proceed. Ordinarily the spray material will dry in 30 minutes of sunshine so that it will adhere well thru any ordinary hard washing rain.

APPLE BLOTCH

Spraying experiments were begun in 1913, primarily to determine efficient methods of control for codling moth, plum curculio, and apple scab, but it was soon discovered that apple blotch was more destructive in some parts of the state than apple scab. The disease was carefully observed during the season and notes taken on the efficiency of the sprays, intended for scab, in controlling blotch. This disease has only recently invaded Nebraska from the south and east and as yet is serious only in the southeastern portion of the State. It is widely distributed over the United States. The writer had abundant opportunity to observe its destructiveness in Kansas in 1910, '11, and '12, where in some sections it causes more damage than any other disease which attacks the apple.

DESCRIPTION AND BEHAVIOR

The fungus attacks fruit spurs, twigs, and rapidly growing shoots, producing characteristic cankers (Scott and Rorer, 1909).

(1909) Scott, W. P. and Rorer, James B. Apple blotch a serious disease of southern orchards. U. S. D. A. Bul. No. 144.

Scott and Rorer further say, in effect: On the fruiting branches the cankers appear first as small purple or blackish blotches. As they increase in size they become brown in the center with a purple margin but finally become gray. The bark soon cracks around the cankers, especially along the lateral edges. On rapidly growing shoots, particularly water sprouts, the cankers have the same

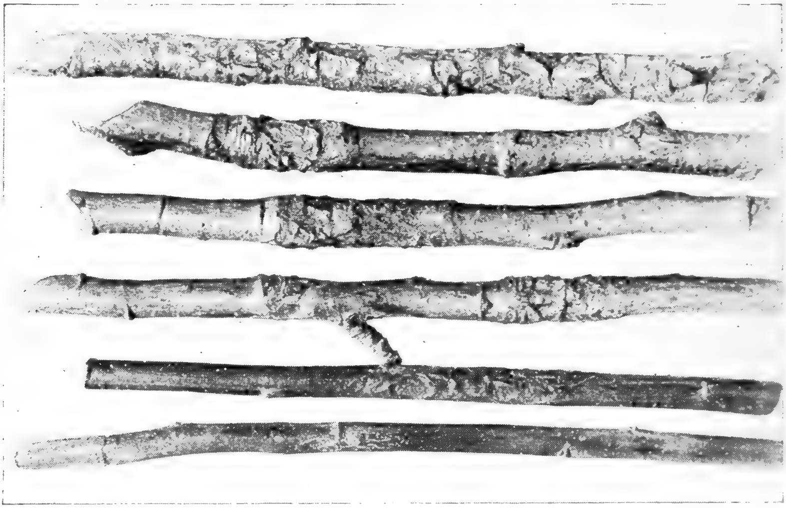


Fig. 9—Blotch cankers on twigs

general appearance as on fruiting branches, but are much larger, often measuring an inch or more in length and sometimes girdling the stem. The fungus lives over winter in the cankers, which become larger from year to year and may continue to grow for several seasons. Frequently, however, the cankers are cut off from the healthy tissue by cracks, dry up, and later the wound may heal over.

The cankers themselves do not, as a rule, seriously injure the tree, but in some cases, on susceptible varieties, such as Northwest Greening, Missouri, Limber Twig, and Red Astrachan, the trees may become so badly affected that much of the bearing wood will be killed and the trees materially weakened. The leaves also are attacked, the fungus causing irregular light brown, yellowish, or whitish spots, measuring 1/16 inch or less in diameter. The spots often appear in great numbers scattered promiscuously over the surface of the leaf, on the veins, midrib, and petiole. The

badly infected leaves may turn yellow and drop prematurely, or die, turn brown, and remain on the tree. This results in a weakening and in many cases the death of the fruit buds for the following year's crop.

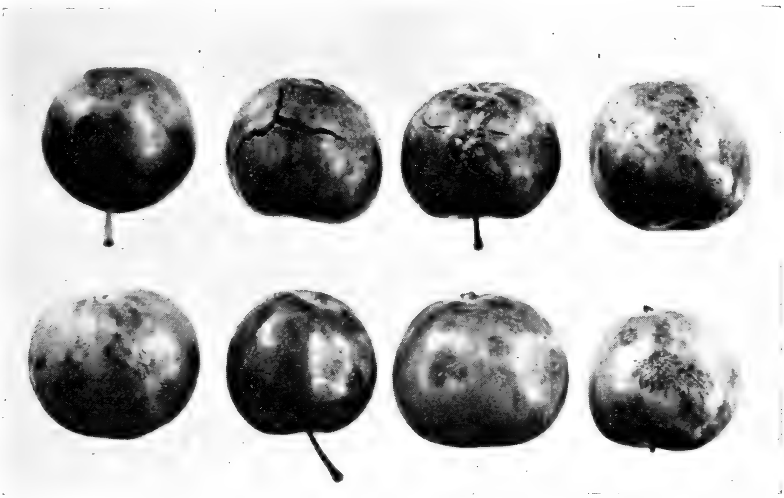


Fig. 10—Blotch on young fruit

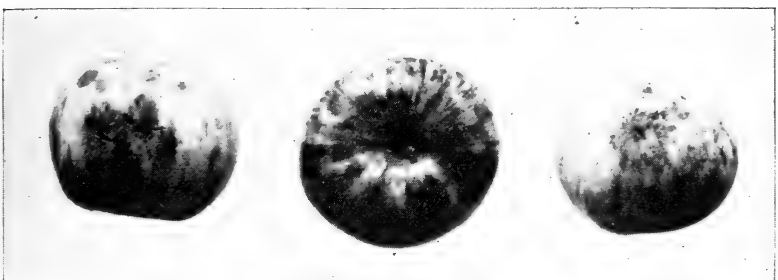


Fig. 11—Blotch on mature fruit

"The first evidence of the disease on the fruit is a very small, inconspicuous light brown blot which under a hand lens has the appearance of a stellate collection of brown fibers just beneath the epidermis."

The blotch spreads rapidly until it attains a size of from one-eighth to three-eights of an inch or even larger and becomes

darker in color. The advancing margin is irregular and jagged and has a fringed appearance. Where the spots are numerous they often coalesce and form large blotches which may cover half or more of the fruit. The fungus kills only the superficial cells so that the continued growth of the tissue beneath results in a cracking of the diseased areas. These cracks tho usually small may girdle the fruit and extend to the core. The general effect is to mar the appearance of the fruit and render it unfit for packing.

INFECTION

According to Scott and Rorer the cankers in which the fungus passes the winter are the chief source of infection. Spores are produced during the warm, moist weather of spring, which are readily carried by the rain and other agencies to the young fruit, leaves, and twigs, producing the first spring outbreak of the disease. The primary and most extensive infection begins 4 to 5 weeks after the petals have fallen, altho some infection probably occurs during the remainder of the growing season.

EXPERIMENTS IN 1913

No special attention was given to blotch when the schedules for 1913 were outlined, but notes were taken on time and amounts of infection and the degree of control afforded by each schedule.

TABLE 33—*Wymore spray schedule*

Date Spray	April 21 Cluster-bud	May 5 Petal-fall	May 22 Three-weeks	July 2 Second-brood
Plat 1	LS-1.5-50	Bx-3-4-50	Bx-3-4-50	Bx-3-4-50
2	LS-1.5-50	LS-1.5-50	Bx-3-4-50	Bx-3-4-50
3	LS-1.5-50	LS-1.5-50	LS-1.5-50	LS-1.5-50
4	Bx-3-4-50	LS-1.5-50	LS-1.5-50	Bx-3-4-50

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Two Ben Davis and two Missouri Pippin trees in each plat	1	1,863	4	.21	49	2.63
	2	3,182	24	.75	192	6.03
	3	2,022	393	19.43	152	7.52
	4	3,405	553	16.24	216	6.34
	check	2,203	551	25.01	......	....

At Wymore (table 33), the efficiency of the lime sulphur schedule (plat 3) was only 23 per cent, while that of the Bordeaux schedule (plat 1) was 99 per cent, and of plat 2 was 97 per cent. This indicates that the application of Bordeaux made three weeks

after the falling of the petals prevented most of the infection. The fact that the Bordeaux spray applied July 2 was slightly more efficient than lime sulphur applied at the same time indicates that some infection occurred after that date.

The first blotch spots were found on the fruit on July 3, about 7 weeks after the petals had fallen from the trees. This would indicate that the infection occurred not more than 4 weeks after the petals fell.

TABLE 34—*Brownville spray schedule*

Date Spray	May 6 Petal-fall	May 30 Three-weeks
Plat 1	LS–1.5–50	LS–1.5–50
2	LS–1.5–50	Bx–3–4–50
3	LS–1.5–50	Bx–3–4–50
7	Bx–3–4–50	Bx–3–4–50

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis and Missouri Pippin, two trees of each variety to a row examined	1	4,790	473	9.87	49	1.02
	2	5,774	298	5.16	40	.69
	3	4,638	100	2.16	15	.32
	7	5,071	127	2.50	2,132	42.04
	check	1,804	437	24.22	......	....

At Brownville (table 34), the evidence indicates that the three-weeks spray controlled the greater part of the infection. Bordeaux used at this time was 31.8 per cent more efficient than lime sulphur. Bordeaux used for the petal-fall spray showed no advantage over lime sulphur, but on the other hand greatly injured a high per cent of the crop. The indications are that the heavy infection occurred soon after the three-weeks spray and that some infection occurred later in the season.

EXPERIMENTS IN 1914

Special stress was laid on determining the date and length of the infection period as well as methods of control. Observations were made in an unsprayed orchard near Lincoln and in the orchards where spraying was done. Spores were found issuing from the cankers in large numbers on June 5 at Beatrice and Wymore and on June 8 at Lincoln. Spores may have been freed before this time. As blotch cankers were not plentiful at Beatrice or Wymore it was impossible to secure definite data at these places. At

Lincoln they were more plentiful and spores continued to issue from some of them for nearly three weeks in large numbers, and in greatly reduced numbers for several days longer. The spray schedules were so arranged that plats could be sprayed at intervals of about 10 days during the heavy dissemination of spores. The severe injury due to Bordeaux russeting, together with the fact that Bordeaux proved more efficient than lime sulphur, led to an interchange of Bordeaux and lime sulphur applications in some of the schedules in order to ascertain if it were not possible to control blotch with a minimum amount of injury.

TABLE 35—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 15 Petal-fall	May 25 10-days	June 12 25-days	June 22 35-days	July 14 2d-brood
Plat 1	Bx-4-6-50	LS-1.008	....	....	LS-1.008	LS-1.008
2	Bx-4-6-50	LS-1.008	....	LS-1.008	....	LS-1.008
3	Bx-4-6-50	LS-1.008	LS-1.008	....	....	LS-1.008
4	Bx-4-6-50	LS-1.008	....	....	Bx-3-4-50	LS-1.008
5	Bx-4-6-50	LS-1.008	....	Bx-3-4-50	....	LS-1.008
6	Bx-4-6-50	LS-1.008	Bx-3-4-50	....	....	LS-1.008

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis	1	772	7	.91	27	3.50
	2	3,248	12	.37	96	2.96
	3	3,485	17	.49	173	4.96
	4	5,342	19	.36	362	6.78
	5	6,074	8	.13	449	7.39
	6	2,198	0	.0	86	3.91
	check	4,377	470	10.74	....	....
Mo. Pippin	1	7,801	230	2.95	90	1.15
	2	7,994	173	2.16	191	2.39
	3	6,128	182	2.97	98	1.60
	4	6,791	58	.85	66	.97
	5	8,098	70	.86	143	1.77
	6	8,141	30	.37	229	2.57
	check	10,468	1,370	13.09	....	....
Ben Davis Mo. Pippin	1	8,573	237	2.76	117	1.36
	2	11,242	185	1.65	287	2.55
	3	9,613	199	2.07	271	2.81
	4	12,133	77	.63	428	3.52
	5	14,172	78	.55	592	4.1
	6	10,339	30	.29	295	2.85
	check	14,845	1,840	12.39	....	....

At Beatrice (table 35), Bordeaux proved only 11 per cent more efficient than lime sulphur. Since the 35-days spray prevented practically as much injury as either of the two preceding sprays, it would indicate that most of the infection did not take place until or after this time.

TABLE 36—*Wymore spray schedule*

Date Spray	April 23 Cluster-bud	May 14 Petal-fall	June 10 Three-weeks	July 12 Second-brood
Plat 1	Bx–4–6–50	Bx–3–4–50	Bx–3–4–50	Bx–3–4–50
2	LS–1.009	LS–1.008	LS–1.008	LS–1.008

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis Mo. Pippin	1	5,703	44	.77	180	3.16
	2	5,603	292	5.21	156	2.78
	check	4,063	100	2.46	....	....

At Wymore (table 36), Bordeaux again proved superior to lime sulphur in controlling blotch. There was considerable more blotch injury on the lime sulphur plat than on the check plat. The check plat was sprayed four times with Bordeaux in 1913. This may account for the lack of infection in 1914.

The results of the work in 1914, while not conclusive, shed considerable light on the possibility, and methods, of controlling blotch. Considering the time when the first spores were liberated, if the proper weather conditions exist infection should begin about three weeks after the petals fall. The finding of some blotched fruit on July 8 at Lincoln and July 10 at Beatrice would also indicate that infection may occur earlier than was suggested by Scott and Rorer. Lewis (1913) also suggested that this was the case in Kansas. However, the fact that the 35-days spray was almost as efficient in controlling the disease as the 10-days or the 25-days spray shows that most of the infection occurred not sooner than 5 weeks after the petals had fallen. As in 1913, Bordeaux proved more efficient than lime sulphur.

EXPERIMENTS IN 1915

The same general plans of procedure were followed as in 1914, except that the experiments for the control of blotch were confined

(1913) Lewis, D. E. The control of apple blotch. Kansas Sta. Bul. 196.

to one orchard. Observations were made chiefly at Lincoln. Spores were found exuding on June 2. They were more abundant than in 1913 or 1914, and could be found in fairly large quantities for 20 days and in smaller quantities for several days longer.

TABLE 37—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 25 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1......	Bx–4–4–50	LS–1.009	LS–1.009	....	....	LS–1.008
2......	LS–1.01	LS–1.009	Bx–4–4–50	....	....	LS–1.008
3......	LS–1.01	LS–1.009	....	Bx–4–4–50	....	LS–1.008
4......	LS–1.01	LS–1.009	LS–1.009	....	Bx–4–4–50	LS–1.008
5......	LS–1.01	LS–1.009	LS–1.009	....	....	LS–1.008

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis....	1	1,602	237	14.79	84	5.24
	2	2,303	0	.0	425	18.45
	3	3,069	53	1.73	328	10.69
	4	1,733	3	.17	130	7.50
	5	878	166	18.91	34	3.87
	check	6,853	2,217	32.35	....	....
Mo. Pippin....	1	1,510	551	36.49	8	.53
	2	1,109	84	7.57	123	11.09
	3	2,631	27	1.03	250	9.50
	4	2,037	58	2.85	16	.78
	5	2,417	501	20.73	80	3.31
	6[1]	1,996	849	42.53	176	8.82
	check	5,966	3,320	55.65	....	....
Ben Davis Mo. Pippin	1	3,112	788	25.32	92	2.96
	2	3,412	84	2.46	548	16.06
	3	5,700	80	1.40	578	10.14
	4	3,770	61	1.62	146	3.87
	5	3,295	667	20.24	114	3.46
	6[2]	1,996	849	42.53	176	8.82
	check	12,819	5,537	43.20	....	....

The evidence shown in table 37 indicates that while some infection must have taken place earlier, the greater part of it occurred after the 35-days spray. Blotched apples were first found the last of June. This also indicates early infection.

[1]Not sprayed in 1914. Received same treatment as plat 5 in 1915.
[2]No Ben Davis.

Bordeaux proved to be higher in efficiency than lime sulphur but the 14-days application did considerable damage by russeting the fruit. The 21-days application did more damage than the 35-days spray. Plat 6 showed almost as much infection as the check plat. Here, however, only the variety Missouri Pippin was considered. This variety is much more susceptible to blotch than the Ben Davis.

TABLE 38—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 25 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1	Bx–4–4–50	LS–1.009	LS–1.009	....	....	....
2	LS–1.01	LS–1.009	Bx–4–4–50	....	....	....
3	LS–1.01	LS–1.009	....	Bx–4–4–50	....	....
4	LS–1.01	LS–1.009	LS–1.009	....	Bx–4–4–50	....
5	LS–1.01	LS–1.009	LS–1.009	....	....	....

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis	1	1,427	162	11.35	207	14.51
	2	1,353	6	.44	242	17.88
	3	1,848	19	1.03	119	6.44
	4	1,853	18	.97	86	4.64
	5	1,938	220	11.35	79	4.08
	check	6,853	2,217	32.35	....	....
Mo. Pippin	1	1,729	391	22.61	9	.52
	2	665	58	8.72	61	9.17
	3	3,069	53	1.73	328	10.69
	4	1,784	28	1.57	132	7.40
	5	1,351	328	24.28	79	5.85
	check	5,966	3,320	55.65	....	....
Ben Davis Mo. Pippin	1	3,156	553	17.52	216	6.84
	2	2,018	64	3.17	303	15.01
	3	4,917	72	1.46	447	9.09
	4	3,637	46	1.26	218	5.99
	5	3,289	548	16.66	158	4.80
	check	12,819	5,537	43.20	....	....

The evidence shown in table 38 corroborates that shown in table 37. In addition it indicates that a lime sulphur application on August 10 was of no value for control of blotch. Here it will be noticed that in contrast to table 37 lime sulphur for the 14-days spray was 61.5 per cent efficient. In fact, the efficiency of the

schedules for both plats 1 and 5 was for some unaccountable reason considerably higher than for the corresponding plats in table 37.

TABLE 39—*Beatrice spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 25 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1	Bx–4–4–50	LS–1.009	LS–1.009	....	....	Bx–4–4–50
2	LS–1.01	LS–1.009	Bx–4–4–50	....	....	Bx–4–4–50
3	LS–1.01	LS–1.009	....	Bx–4–4–50	....	Bx–4–4–50
4	LS–1.01	LS–1.009	LS–1.009	....	Bx–4–4–50	Bx–4–4–50
5	LS–1.01	LS–1.009	LS–1.009	....	....	Bx–4–4–50

Blotch injury on windfalls and picked fruit

Variety	Plat	Total fruit	Blotch	Per cent blotch	Spray injury	Per cent spray injury
Ben Davis	1	2,112	224	10.60	551	26.09
	2	....	....	....	....	....
	3	4,711	2	.04	606	12.86
	4	....	....	....	....	....
	5	1,727	217	12.56	58	3.36
	check	6,853	2,217	32.35	....	....
Mo. Pippin	1	....	....	....	....	....
	2	....	....	....	....	....
	3	....	....	....	....	....
	4	2,084	32	1.54	159	7.63
	5	1,067	230	21.55	48	4.50
	check	5,966	3,320	55.65	....	....
Ben Davis Mo. Pippin	1[1]	2,112	224	10.60	551	26.09
	2	....	....	....	....	....
	3[1]	4,711	2	.04	606	12.86
	4[2]	2,084	32	1.54	159	7.63
	5	2,794	447	16.00	106	3.79
	check	12,819	5,537	43.20	....	....

The results shown in table 39 are quite similar to those of the two preceding tables. In this case, however, the 21-days spray shows an efficiency of 100 per cent and practically as much is shown for the 35-days spray, but the 14-days spray permitted some infection. The writer is of the opinion that infection did not take place until after the 14-days spray, and the Bordeaux, being effective for a longer period than lime sulphur, prevented infection. It is very probable that some infection occurred on plat 4 before the spray was put on.

[1]No Mo. Pippin.
[2]No Ben Davis.

INCIDENTAL OBSERVATIONS

At Brownville in 1913, considerable summer pruning was done on plat 3. This consisted in the removal of dead and diseased wood and a general thinning out of the tops of the trees. At this time all blotch cankers which could be found were removed. To no other reason can be ascribed the difference in amount of blotch on plats 2 and 3. This difference, while not extraordinary, indicates what may be accomplished in this way. The greatest amount of infection seems to occur from about 3 to 5 weeks after the petals fall. The exact time between these two dates depends upon weather conditions. Infection occurs more readily and abundantly if the weather is warm and moist.

Blotch attacks fruit spurs as well as small branches and water sprouts. At the Hartley orchard, north of Lincoln, an examination of a number of Mann apple trees revealed the fact that on two of these which were infected the worst, 20 per cent of the spurs were dead and on the remaining spurs more than 30 per cent of the buds were killed. This mortality could be attributed only to blotch injury, since the trees were otherwise in a good state of health.

Grouped according to susceptibility as observed during the last three seasons, the common varieties rank as follows:

Practically resistant	*Moderately resistant*	*Susceptible*
Grimes (Golden)	Lawver	Mann
York (Imperial)	Ralls (Jenet)	Missouri (Pippin)
Winesap	Minkler	Maiden Blush
Stayman	Rome	Northwest Greening
Wealthy	Arkansas (Mammoth Blacktwig)	Ben Davis
	Arkansas Black	

This list is very short, owing to the lack of varieties in the orchards under observation. As in the case of resistance to scab, there was some variation of the comparative resistance of the different varieties.

SUMMARY

The results of experiments and observations during the past three seasons indicate that apple blotch on the fruit can be controlled entirely by spraying alone, but the eradication of the disease may be facilitated by supplementing a thoro spraying campaign with the pruning out of affected wood.

Bordeaux was found more effective than lime sulphur, but at the same time it was found to cause considerable injury to the fruit by russeting it. The injury was found to be greatest when Bordeaux was used at or soon after the time when the petals fall.

Injury from russeting gradually diminishes as the apples become larger, altho there is always more or less danger in employing this fungicide even late in the season. When the mixture is properly made, the injury from Bordeaux compared with the advantages of its use, in combating blotch, is so small that in badly infected orchards it is recommended for the 3-weeks spray and subsequent applications.

For this purpose the 3–4–50 formula is recommended, tho if a good grade of fresh stone lime is used (not air-slacked or hydrated lime) the 3–3–50 formula is equally good. During dry weather the 4–4–50 formula has given good results but is not so safe when used during wet weather.

The indications are that three weeks after the petals fall is soon enough for the first spray for blotch, and in orchards no more badly infected than were those in which the records were made, i.e., 12 per cent to 45 per cent, this spray, followed by another application of fungicide when spraying for the second brood of codling moth, is usually sufficient. In orchards more heavily infected, no doubt another application of Bordeaux, 15 to 20 days after the 3-weeks spray, would prove very beneficial.

CEDAR RUST ON APPLES

During the three seasons just past, sufficient data could not be secured to warrant any statements by the writer on methods of controlling this disease. The comparatively dry seasons preceding these experiments probably did not offer the best conditions for the advancement of the disease. A report published

Fig. 12—Cedar rust on fruit

from this Station by Emerson in 1913 shows that the first or cluster-bud spray has comparatively no effect on the amount of injury from rust, but that the petal-fall spray and the one following give a very high per cent of control.

Fig. 13—Cedar rust on apple leaves

In order to secure the best results, spraying should be given as soon as the knots on the cedar trees known as "cedar apples" begin to enlarge and show gelatinous orange-colored exudations. This orange-colored mass contains the spores which spread to the apple trees and produce the well-known orange-colored blemishes on fruit and leaves.

SOOTY BLOTCH AND FLYSPECK

Sooty blotch and flyspeck are considered by most pathologists to be caused by the same fungus and were so treated in the

observations on which this report is based. The fungus attacks the fruit late in the season and is entirely superficial, the loss being due to discoloration, reducing the salability of the fruit. The fungus is most abundant during wet seasons and does the most damage to fruit in the lower parts of the orchard where air drainage is poor or where the trees stand too close together or are not properly pruned.

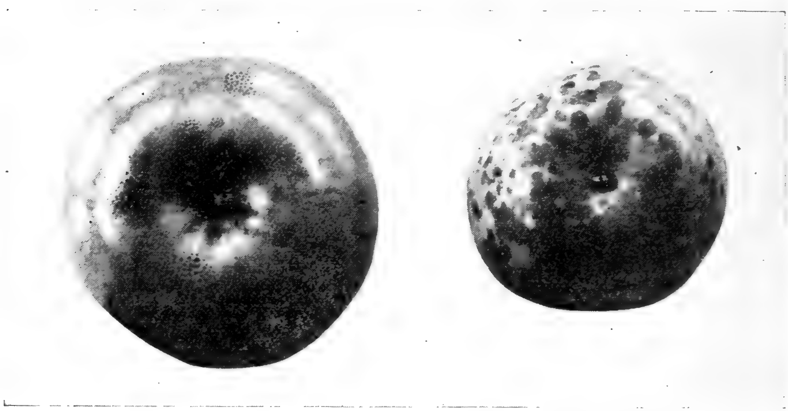


Fig. 14—Sooty blotch or flyspeck on fruit

Observations indicate that with proper pruning to admit air and light the disease will be incidentally controlled in spraying for blotch and scab.

BORDEAUX VS. LIME SULPHUR

Bordeaux has long been considered as the specific for all fungous diseases and has upheld its reputation in so far as controlling diseases is concerned. However, a great deal of injury to fruit and foliage often accompanies its use. In searching for a substitute, lime sulphur was found to be the most satisfactory material as a fungicide. Its fungicidal properties may not be quite so pronounced as those of Bordeaux, but the small amount of injury accompanying its judicial use, together with its insecticidal value, often makes it more desirable than Bordeaux. Experiments were begun at this Station to determine the relative value of each for general spraying purposes. The three seasons during which the tests were carried on offer ample variations in weather conditions to permit of rather general conclusions as to the value of each and the conditions which encourage injury from the use of either.

EXPERIMENTS IN 1913

In addition to the data on this subject given in connection with scab and blotch control, data were taken as to the effect of Bordeaux and lime sulphur on insects and diseases in general as well as to the amount of sound, clean fruit resulting from the use of either material. In making Bordeaux, the orthodox method of mixing was followed, i. e., the diluted lime and copper sulphate were poured simultaneously into a mixing tank or into the spray tank. A high grade of lime was used and all coarse material, grit, etc., removed by straining.

TABLE 40—*Spray schedule*

Date Spray	April 25 Cluster-bud	May 5 Petal-fall	May 22 3-weeks	July 2 Second-brood
Plat 1	LS–Pb 1.5–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
2	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
3	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	Bx–Pb 3–4–2–50
4	Bx–Pb 3–4–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	Bx–Pb 3–4–2–50

Comparison of the effect of Bordeaux and lime sulphur
Tabulations indicate percentages

Variety	Plat	Codling moth	Curculio		Scab	Blotch	Sooty blotch	Spray injury	Sound fruit
			worms	stings					
Ben Davis Mo. Pippin	1	11.00	.21	.53	......	.21	......	2.63	86.80
	2	10.74	.126	.56	......	.75	......	6.03	83.03
	3	11.17	.49	.44	.05	19.44	......	7.52	78.54
	4	11.07	.17	.53	.03	16.24	......	6.34	80.53
	check	49.02	.59	9.71	8.58	25.01	1.91	......	12.21

No rust was present on any of the trees.

At Wymore (table 40), there was little or no evidence of any difference in the amount of insect infestation. Scab was equally well controlled by either fungicide. Bordeaux, however, showed decidedly more efficiency in controlling apple blotch, the difference in efficiency being approximately 69 per cent. There was practically no difference in the amount of spray injury. The lack of Bordeaux injury on the fruit is no doubt due to the fact that dry weather followed the applications. Bordeaux injury to the foliage was quite noticeable. This was also true of lime sulphur injury. The higher percentage of sound fruit, i. e., fruit free from any insect or fungous injury or spray russet, in plats 1

and 2 is due chiefly to the presence of blotch, which, as has already been shown, is more thoroly controlled by Bordeaux.

TABLE 41—*Spray schedule*

Date Spray	April 24 Cluster-bud	May 10 Petal-fall	June 3 3-weeks	July 16 Second-brood
Plat 1.......	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
2.......	Bx–Pb 3–4–2–50	LS–Pb 1.5–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
3.......	Bx–Pb 3–4–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	Bx–Pb 1.5–2–50
4.......	Bx–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50
5.......	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50
6.......	Bx–Pb 3–3–2–50	Bx–Pb 3–3–2–50	Bx–Pb 3–3–2–50	Bx–Pb 3–3–2–50
7.......	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50	LS–Pb 1.5–2–50

Comparison of the effect of Bordeaux and lime sulphur
Tabulations in percentages

Variety	Plat	Codling moth	Curculio worms and stings	Scab	Sooty blotch	Spray injury	Sound fruit
Ben Davis Winesap	1	12.94	.08	1.05	....	29.37	64.19
	2	10.44	.15	1.90	....	19.18	70.49
	3	11.18	.13	1.71	....	16.48	73.48
	4	12.70	.44	1.00	....	9.01	77.29
	5	7.66	.14	3.25	....	7.98	81.06
	6	8.12	.80	.03	....	28.54	69.01
	7	8.03	2.54	1.74	....	8.63	82.94
	check	69.59	8.67	24.60	.85	....	10.29

No blotch or rust was present on any of the fruit.

At Florence (table 41), there is no conclusive evidence in favor of either fungicide except in the amount of spray injury. The greatest injury occurred where Bordeaux was used for the petal-fall spray.

The weather conditions were such as to induce the most serious burning by either fungicide. High hot winds prevailed during the petal-fall spray, followed by wet weather. Wet weather followed the 3-weeks application. The last application was made just after a severe hailstorm which had injured both fruit and foliage to a considerable extent, and was followed by two days of extremely hot weather after which came more rain. Both fruit and foliage were badly burned. The use of an excess of lime

in making the Bordeaux was of no advantage in preventing spray injury.

The amount of sound fruit here on the different plats seems to have been in inverse proportion to the spray injury.

TABLE 42—*Spray schedule*

Date Spray	April 25 Cluster-bud	May 9 Petal-fall	June 2 3-weeks	July 15 Second brood
Plat 1.......	Bx–Pb 3–4–3–50	Bx–Pb 3–4–3–50	Bx–Pb 3–4–3–50	Bx–Pb 3–4–3–50
2.......	Bx–Pb 3–4–3–50	LS–Pb 1.5–3–50	LS–Pb 1.5–3–50	Bx–Pb 3–4–3–50
3.......	LS–Pb 1.5–3–50	LS–Pb 1.5–3–50	LS–Pb 1.5–3–50	LS–Pb 1.5–3–50
4.......	Bx–Pb 4–4–3–50	Bx–Pb 4–4–3–50	Bx–Pb 4–4–3–50	Bx–Pb 4–4–3–50

Comparison of the effect of Bordeaux and lime sulphur
Tabulations are in percentages

Variety	Plat	Codling moth	Curculio worm and sting	Scab	Spray injury	Sound fruit
Ben Davis Jonathan....	1	13.70	1.43	.26	30.79	54.14
	2	10.71	.94	.078	19.53	76.85
	3	10.71	.49	1.05	8.75	86.70
	4	20.78	.27	.65	21.21	59.20
	check	33.20	5.86	34.85	....	34.08

No blotch, sooty blotch, or rust was present.

At Lincoln (table 42), the results were practically the same as at Florence. Bordeaux made according to the 4–4–50 formula was no more effective than the 3–4–50 Bordeaux. Neither did it cause any more injury; in fact the injury on this plat was less than in plat 1. There was one tree in plat 1 which had much more injury than any other tree of either plat.

There was more codling moth injury on the Bordeaux plats than on the lime sulphur plats. This difference is attributed to some extent to the greater amount of spray injury found on the former. The damage was done chiefly by second-brood larvæ which entered thru the roughened parts of the skin, these places affording an easier entrance than the smooth, hard surface of the unrusseted portions. Again, there might have been a less thoro covering of poison over this part of the apple, due to the malformation of the fruit after the spraying was done.

Considerable injury to foliage also occurred on the Bordeaux plats.

EXPERIMENTS IN 1914

It was planned to follow the same general methods as in 1913 except at the Station. The Bordeaux was made by placing the copper sulphate in the tank and diluting, then adding the diluted lime. At the Station, the ingredients were diluted and poured together into the spray tank.

TABLE 43—*Spray schedule*

Date Spray	April 24 Cluster-bud	May 15 Petal-fall	May 25 10-days	June 12 25-days	June 22 35-days	July 14 2d-brood
Plat 1	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	....	....	LS–Pb 1.008–2	LS–Pb 1.008–2
2	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	....	LS–Pb 1.008–2	....	LS–Pb 1.008–2
3	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	LS–Pb 1.008–2	....	....	LS–Pb 1.008–2
4	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	....	....	Bx–Pb 3–3–2–50	LS–Pb 1.008–2
5	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	....	Bx–Pb 3–3–2–50	....	LS–Pb 1.008–2
6	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	Bx–Pb 3–3–2–50	....	....	LS–Pb 1.008–2

Comparison of the effect of Bordeaux and lime sulphur
Tabulations are in percentages

Variety	Plat	Codling moth	Curculio worm and sting	Scab	Blotch	Spray injury	Sound fruit
Ben Davis	1	50.00	.39	1.04	.91	3.50	45.21
	2	38.85	.0	.98	.37	2.96	56.83
	3	34.09	.0	.34	.49	4.96	60.80
	4	29.72	.03	.30	.35	6.78	64.53
	5	31.02	.016	.25	.13	7.39	61.41
	6	31.66	.0	.73	.0	3.91	64.97
	check	66.32	2.58	10.60	10.74	......	31.85
Mo. Pippin	1	31.27	.02	.85	2.95	1.15	64.98
	2	28.66	.0	.54	2.16	2.39	67.02
	3	28.07	.0	.32	2.97	1.60	69.24
	4	27.06	.0	.41	.85	.97	71.11
	5	21.09	.01	.15	.86	1.77	76.64
	6	39.07	.0	.12	.37	2.57	58.01
	check	77.58	2.67	12.48	13.08	......	16.77
Ben Davis Mo. Pippin	1	32.95	.059	.86	2.76	1.36	63.20
	2	31.60	.0	.67	1.65	2.55	63.37
	3	30.25	.0	.33	2.07	2.82	66.18
	4	28.24	.016	.36	.63	3.53	68.21
	5	25.35	.014	.19	.55	4.18	70.11
	6	37.50	.0	.25	.29	2.85	59.50
	check	74.26	2.65	11.93	12.39	......	21.22

No sooty blotch or rust present.

At Beatrice (table 43), there was little difference in the efficiency of the two fungicides except in the control of blotch. Again Bordeaux proved superior to lime sulphur for this purpose. However, the difference in efficiency was only about 11 per cent. There was practically no difference in the amount of spray injury on the fruit. Here dry weather followed each application. There was more injury to the foliage from using lime sulphur than Bordeaux. The damage to foliage noted on the lime sulphur plats greatly resembled that of the Bordeaux plats in that there were the same characteristic brown spots on the leaves. However, the spots were larger and more irregular. In addition, the leaves were burned at the edges and at the tips.

TABLE 44—*Spray schedule*

Date Spray	April 25 Cluster-bud	May 15 Petal-fall	June 14 Three-weeks	July 15 Second-brood
Plat 1	LS–Pb 1.01–2	LS–Pb 1.008–2	LS–Pb 1.008–2	Bx–Pb 3–4–2–50
2	LS–Pb 1.01–2	LS–Pb 1.008–2	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
3	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50
4	LS–Pb 1.01–2	LS–Pb 1.008–2	LS–Pb 1.008–2	LS–Pb 1.008–2

Comparison of the effect of Bordeaux and lime sulphur
Tabulations are in percentages

Variety	Plat	Codling moth	Curculio worm and stings	Scab	Spray injury	Sound fruit
Ben Davis Winesap	1	58.01	.0	.09	4.00	38.33
	2	50.27	.0	.10	3.59	46.68
	3	49.65	.0	.07	4.56	46.99
	4	53.47	.0	.14	4.97	46.36
	check	93.91	2.54	1.90	....	4.13

No blotch or rust was present.

At Lincoln (table 44), there is little evidence in favor of either fungicide except in injury to the foliage. Here lime sulphur did more damage than Bordeaux. The weather at this place was dry after each application.

TABLE 45—*Spray schedule*

Date Spray	April 30 Cluster-bud	May 20 Petal-fall	June 18 3-weeks	July 20 Second-brood
Plat 1.......	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	LS–Pb 1.008–2	Bx–Pb 3–4–2–50
2.......	Bx–Pb 4–6–2–50	LS–Pb 1.008–2	LS–Pb 1.008–2	Bx–Pb 3–4–2–50
3.......	LS–Pb 1.01–2	LS–Pb 1.008–2	LS–Pb 1.008–2	LS–Pb 1.008–2
4.......	LS–Pb 1.01–2	LS–Pb 1.008–2	LS–Pb 1.008–2	LS–Pb 1.008–2

Comparison of the effect of Bordeaux and lime sulphur
Tabulations in percentages

Variety	Plat	Codling moth	Curculio worm and sting	Scab	Sooty blotch	Spray injury	Sound fruit
Ben Davis Winesap	1	23.02	.07	2.42	.0	1.61	74.68
	2	24.13	.10	3.16	1.09	4.82	66.70
	3	27.51	.21	1.99	.0	2.06	68.47
	4	23.29	.13	1.31	.23	2.74	73.61
	check	82.44	2.06	24.47	.76	......	9.99

No blotch or cedar rust was present.

At Seward (table 45), the evidence is again little in favor of either fungicide. No wet weather was encountered for several days after each application. Again lime sulphur caused more injury to the foliage than did Bordeaux.

EXPERIMENTS IN 1915

Experiments were conducted only at Beatrice this year. The test was primarily one of studying the effect of Bordeaux rather than one of comparison of Bordeaux and lime sulphur, tho the data afford some opportunities for comparison.

At Beatrice (table 46), a comparison of the two fungicides for the cluster-bud spray favors lime sulphur as an insect repellent. However, this is not in accordance with previous tests.

Here again Bordeaux did more injury when applied early than when applied later in the season. Considerable Bordeaux injury was noted on the foliage.

TABLE 46—*Spray schedule*

Date Spray	April 24 Cluster-bud	May 5 Petal-fall	May 24 14-days	June 7 21-days	June 21 35-days	Aug. 10 2d-brood
Plat 1	Bx–Pb 4–4–1.5–50	LS–Pb 1.009–1.5	LS–Pb 1.009–1.5	....	....	LS–Pb 1.008–1.5
2	LS–Pb 1.01–1.5	LS–Pb 1.009–1.5	LS–Pb 1.009–1.5	....	....	LS–Pb 1.008–1.5
3	LS–Pb 1.01–1.5	LS–Pb 1.009–1.5	Bx–Pb 4–4–1.5–50	....	....	LS–Pb 1.008–1.5
4	LS–Pb 1.01–1.5	LS–Pb 1.009–1.5	....	Bx–Pb 4–4–1.5–50	....	LS–Pb 1.008–1.5
5	LS–Pb 1.01–1.5	LS–Pb 1.009–1.5	LS–Pb 1.009–1.5	....	Bx–Pb 4–4–1.5–50	Bx–Pb 4–4–1.5–50
6	LS–Pb 1.01–1.5	LS–Pb 1.009–1.5	LS–Pb 1.009–1.5	....	Bx–Pb 4–4–1.5–50	LS–Pb 1.008–1.5

Comparison of the effect of Bordeaux and lime sulphur
Tabulations are in percentages

Variety	Plat	Codling moth	Curculio worm	Curculio sting	Scab	Blotch	Sooty blotch	Spray injury	Sound fruit
Ben Davis	1	11.11	.0	8.24	.69	14.80	3.31	5.24	69.85
	2	4.76	.0	4.57	.25	18.04	.0	5.62	67.03
	3	......	......	......	......	......	......	......	......
	4	......	......	......	......	......	......	......	......
	5	9.08	.0	5.66	1.79	1.57	1.23	7.40	77.91
	6	2.77	.0	5.19	.0	.17	.0	7.50	86.50
	check	32.45	1.81	9.98	85.01	32.35	69.68	......	2.17
Mo. Pippin	1	5.63	.0	2.98	.13	36.49	5.76	.53	58.01
	2	2.69	.08	3.14	4.47	20.73	7.28	3.31	71.95
	3	4.15	.0	2.52	.0	7.57	1.35	11.09	77.10
	4	4.22	.0	4.29	1.48	1.03	.34	9.50	83.16
	5	3.02	.0	2.88	.0	1.54	.0	7.63	84.99
	6	1.42	.0	2.11	.0	2.85	.20	.78	92.64
	check	27.64	.64	5.56	74.71	55.75	79.65	......	2.01
Ben Davis Mo. Pippin	1	8.45	.03	5.69	.42	25.32	4.50	2.96	64.11
	2	3.52	.05	3.72	2.77	19.65	4.36	4.24	69.87
	3[1]	4.15	.0	2.52	.0	7.57	1.35	11.09	77.10
	4[1]	4.22	.0	4.29	1.48	1.03	.34	9.50	83.16
	5	5.82	.0	4.16	.83	1.55	.57	7.52	81.72
	6	2.04	.0	3.53	.0	1.62	.11	3.87	89.81
	check	30.21	1.26	7.93	80.23	43.24	74.32	......	2.10

[1]No Ben Davis.

INCIDENTAL OBSERVATIONS

Bordeaux is never entirely safe where much rain falls during the time when the spray is on the trees.

Some varieties of apples are injured more than others, but no variety is entirely free. The varieties Early Harvest, Ralls, Rome, Chenango, Snow, Missouri, York, and Maiden Blush are perhaps less seriously injured than are the other well-known varieties of apples, but since they are also less important the question of varietal susceptibility can be given little consideration in attempting to eliminate the trouble.

Bordeaux injury first appears on the fruit as small dark-colored spots regular in outline and occurring singly or in long clusters. Usually injury occurs on the upper side of the fruit but not uncommonly almost the entire surface is covered. Soon after the spots are first noticed the skins become roughened. Small ridges or veins connect the different spots so that the skin presents a corky, netted appearance. In cases of severe injury, the apples

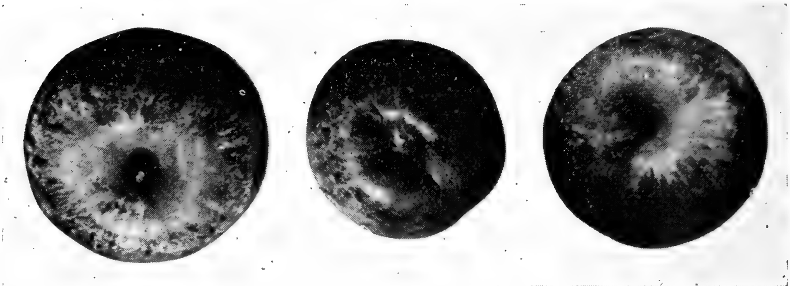


Fig. 15—A light case of Bordeaux injury on fruit

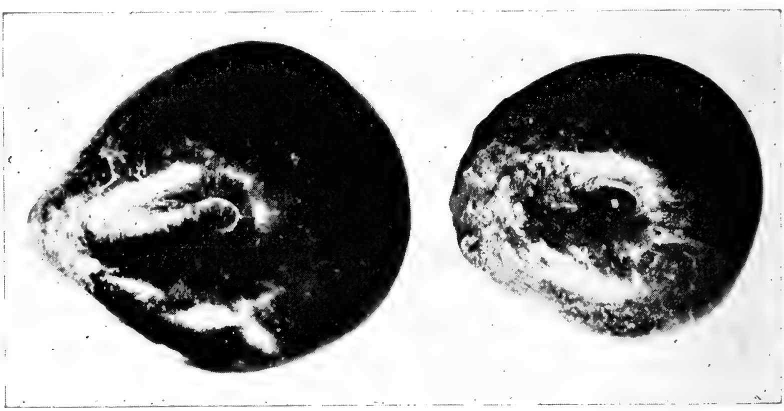


Fig. 16—A severe case of Bordeaux injury on fruit

are often distorted in shape. The growth of the cuticle is checked, while the inner tissues continue to grow. This causes the apple to become lopsided, and often causes cracking similar to that caused by scab and blotch.

On the leaves, Bordeaux injury resembles to some extent the injury caused by some fungi. Brown spots of dead tissue 3 or 4 mm. in diameter appear, at first regular, but as the spots increase in size and coalesce, becoming quite irregular. In cases of severe injury, these spots involve one-third to one-half of the area of the leaf, or more. Soon the remaining portions become yellow, then begin to wither and turn brown, until only the midrib and larger veins remain green; then these succumb and the leaves fall. Sometimes the leaves fall before turning brown. The number of leaves affected varies from a few, scattered over the tree, to almost all the leaves on the tree.

Bordeaux injury usually does not occur for several days after the application and if no rain falls may not occur at all. However, as a rule, enough dew collects to cause some injury even in dry weather. On the foliage the injury was found to be more severe when the leaves had been injured by insects, hail, or other causes. This was also true of the fruit after a hailstorm at Florence.

Lime used in excess does not prevent or lessen to any appreciable extent the injury from Bordeaux russeting. Neither is the application of milk of lime to the trees after Bordeaux has been applied of any appreciable benefit, as shown by table 47.

Lime sulphur causes some injury to both fruit and foliage; but, unlike the injury caused by Bordeaux, it appears almost at once. It causes the most severe injury during hot dry weather. This is no doubt due to the oxidation of the tissues.

On the fruit, lime sulphur injury, when not severe, resembles injury caused by Bordeaux, but in more severe cases the injured surface becomes hard and thickened. Unlike the netted appearance formed in Bordeaux injury, the surface is covered by more or less smooth and dark-colored scales, giving the fruit a scurfy appearance. In the most severe cases, cracks appear on the injured surface, usually near the edges but often crisscrossing the entire surface. This injury is no doubt partly due to sun scald before or during the time when the oxidation of the tissues is taking place. That this must be the case is shown by the fact that the most severe injury is always found on the south and west sides of the trees. The injury before spraying or as it appears on unsprayed trees was much less severe and of a different appearance. Sun scald alone appears first as a brownish discolored spot with a fairly distinct margin. Later, in the most severe cases, the skin becomes sunken and remains smooth and dark. Very little cracking

TABLE 47—*Effect of using milk of lime after rains on plats sprayed with Bordeaux and of using Bordeaux without lime*

Location	Treatment	Application	Total fruit	Scab	Per cent	Blotch	Per cent	Sooty blotch	Per cent	Spray injury	Per cent
Lincoln											
1	3-4-50 Bordeaux	1-2-3-4	1,589	26	1.63	.0	.0	.0	.0	193	12.13
2	3-3-50 Bordeaux	1-2-3-4	954	13	1.36	.0	.0	.0	.0	102	10.73
3	3-4-50 Bordeaux followed by milk of lime after rains	1-2-3-4	1,313	24	1.37	.0	.0	.0	.0	224	12.8

occurs except at the margin of the injured spot. On the sprayed fruit a much larger area is usually affected. Cracking is more pronounced and scales and rays of russet extend far beyond the limits of the sunken corky spots.

Often the most severe injury did not appear for several days after spraying, or until a period of very hot, dry weather and bright sunshine. However, in such cases the injury was rarely so severe as when the spraying was done during a period of extremely hot, dry weather. Bonns (1912) says that the spray affects only that portion of the fruit which has already been injured by sun scald.

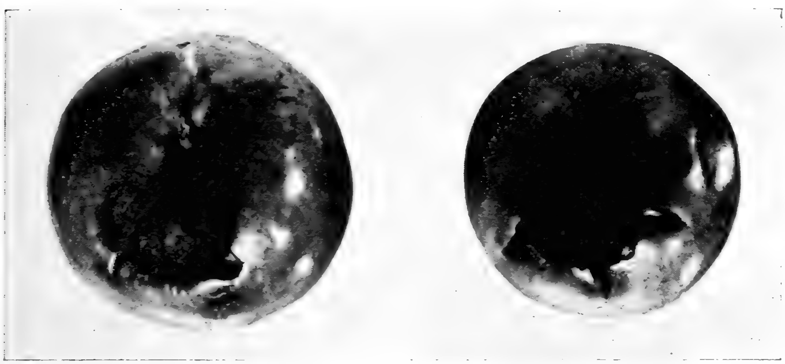


Fig. 17—Lime sulphur injury on fruit

On the foliage, lime sulphur injury appears within the first 12 to 24 hours after applying the spray. The tender new leaves are the first to suffer but in more severe cases the mature leaves are also damaged. The injury appears first at the tips and edges, where the material collects in larger quantities, and gradually extends toward the center of the leaf. Dead, brown spots may also appear over the entire leaf. The general appearance is as tho the leaves had been scorched by fire.

Lime sulphur containing sludge causes more severe burning than where the clear liquid is used. This was demonstrated in a near-by orchard where lime sulphur containing sludge was used on a part of the orchard while the remainder was sprayed with the clear liquid. Both leaves and fruit were damaged where the sludge was used.

(1912) Bonns, W. W. Orchard spraying experiments. Maine Sta. Bul. 198:21.

Grit or hard materials of any kind in the solution may cause russeting by being thrown against the surface of the fruit with considerable force, thus destroying the waxy covering of the cells or the cells themselves and allowing them to be more easily injured by the corrosive action of the spray.

It is the opinion of the writer that a great deal of the so-called spray injury to the leaves is due to infection by fungous diseases. It was noticed that either Bordeaux and lime sulphur injury was as a rule more conspicuous in the orchards where there was an infection of blotch. This was also true of lime sulphur in 1915 in the orchards where the scab infection was most severe. The spray when applied where infection has occurred finds a ready entrance into the leaves at the infected parts and consequently destroys the contents of the surrounding cells, causing the well-known spotting. This has also been noted consistently in other orchards, the spray injury in the form of spotting of the leaves occurring more abundantly in orchards infected with blotch or scab and appearing in greater numbers after the last spray of the summer.

Hedrick (1907) states that the scab fungus often causes a russet closely resembling spray injury to appear on apples and pears. He also mentions the resemblance of Bordeaux injury on the foliage to the injury caused by species of Phyllosticta. Stewart and Eustace (1902) found that the spots caused by Bordeaux injury were free from the pycnidia or Phyllosticta in early summer, July 10, but that later the majority of the spots contained a species of *Phyllosticta*, but they raise the question as to whether the fungus does not appear as a saprophyte after the Bordeaux has caused the injury.

As a rule, even where russeting is negligible, fruit sprayed with Bordeaux is not so bright colored and attractive as fruit sprayed with lime sulphur. Tiny gray flecks are scattered over the surface, marring the otherwise smooth, waxy appearance. This condition, however, is not so noticeable where Bordeaux is used during the latter part of the season and is not followed by rain.

SUMMARY

The results of the three years' work with Bordeaux and lime sulphur indicate that Bordeaux is very little if any more effective than lime sulphur as a fungicide under Nebraska conditions, except in the control of apple blotch.

The danger of injuring the fruit which accompanies the use of Bordeaux makes its use inadvisable except where serious infections of blotch occur.

(1907) Hedrick, U. P. Bordeaux injury. New York (Geneva) Exp. Sta. Bul. 287:139.

(1902) Stewart, F. C., and Eustace, H. J. Two unusual troubles of apple foliage. (Pt. ii) New York Sta. Bul. 220:225-233.

Bordeaux injury is most severe during wet weather and on young fruit.

Lime sulphur injury is most severe during dry weather.

The 3–3–50 Bordeaux has proven as efficient for spraying apples as any other formula.

Bordeaux injury cannot be materially reduced by using an excess of lime or by applying lime after spraying with Bordeaux.

HOME BOILED VS. COMMERCIAL LIME SULPHUR

The comparatively high cost of commercial lime sulphur has induced a number of growers to attempt to manufacture their own solution. Such varying degrees of success have accompanied these efforts that it was decided to conduct a series of tests to determine the relative value of the two solutions. Only one year's work is reported.

TABLE 48—*A comparison of the effect of home boiled vs. commercial concentrated lime sulphur*

Variety	Plat	Total fruit	Scab	Per cent	Spray injury	Per cent
Winesap	[1]1	1,893	575	30.38	15	.79
Ben Davis	[1]	1,705	506	29.68	71	4.16
Winesap	......	1,737	208	11.97	74	4.26
Arkansas	......	926	66	7.13	25	2.70
Jonathan	......	2,415	0	.00	65	2.69
Malinda	......	2,831	63	2.22	651	23.00
Virginia Beauty	......	2,964	177	5.97	292	9.85
Grimes	......	1,506	22	1.46	161	10.69
		15,977	1,617	10.12	1,354	8.49
Winesap	[1]2	1,499	571	38.09	43	2.87
Ben Davis	[1]	1,871	573	30.62	108	5.77
Winesap	......	1,036	141	13.61	52	5.02
Arkansas	......	658	47	7.14	17	2.58
Jonathan	......	972	1	.10	123	12.65
Malinda	......	2,667	36	1.35	880	33.00
Virginia Beauty	......	1,376	125	9.09	200	14.53
Grimes	......	2,120	32	1.51	359	16.93
		12,199	1,526	12.51	1,782	14.61

Plat 1 was sprayed four times with home boiled lime sulphur, 1.009 specific gravity.

Plat 2 was sprayed four times with commercial lime sulphur made up to the same strength.

[1]These trees stood close to check trees which were heavily scabbed.

Altho the evidence in table 48 is not conclusive, it at least indicates that the home boiled product is as effective when properly

made as the commercial brands. Slightly less spray burn was recorded for the plats sprayed with the home boiled solution. If spray injury is due to the rapid oxidation of the sulphur compounds, this might be expected, since of the total sulphur content of the home boiled solution approximately 62.5 per cent was polysulphides, (CaS_5 and CaS_4), while the polysulphides in the commercial solution amounted to approximately 75.4 per cent of the entire sulphur content.

The results shown in tables 31 and 32 are for home boiled lime sulphur.

COMMERCIAL PREPARATIONS SOLD AS FUNGICIDES

Several preparations, sold as fungicides by various companies, have been tried out, but so far nothing has been found to take the place of the two standard fungicides. Several brands of prepared Bordeaux were found to control fungous diseases practically as well as the regular Bordeaux but did considerably more damage to fruit and foliage.

Atomic sulphur and soluble sulphur were used with the results that scab was usually controlled but the damage to fruit and foliage was so great as to make the use of either disastrous. Sulphur in either form would be desirable because of convenience in handling and reduction in freight, could the disagreeable feature of injury to the fruit be eliminated.

PENETRATION VS. MIST SPRAYING

There has been so much discussion in regard to the manner of applying spray materials, so many arguments advanced favoring both high and low pressure solid-stream and hollow-stream nozzles, etc., etc., that it is difficult to determine which method or combination of methods to follow. Unfortunately for the man who studies bulletins from every station, hoping thereby to model his own course of procedure, there is such a wide range of climatic and other conditions that what is true for one section of the country will not obtain for another. Especially is this true in attempting to compare eastern and western methods of fruit growing. And, while the penetration method of spraying, i.e., applying the liquid with solid-stream nozzles under high pressure, gives good results under Washington conditions, it does not necessarily follow that it will give equally good results under such conditions as obtain in the Middle West.

The foregoing report on codling moth control shows that the spray applied as a coarse mist under 225 to 250 pounds pressure is as effective for the calyx application as where applied with the

solid-stream type of nozzle under the same or higher pressure. The following tables afford a comparison for each of the principal sprays.

TABLE 49—*Nemaha spray schedule*

	Cluster-bud	Petal-fall	3-weeks	Second-brood	
Plat 1......	Bx–3–4–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	Bx–Pb 3–4–2–50	mist
2......	Bx–3–4–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	Bx–Pb 3–4–2–50	penetration
3......	LS–Pb 1½–2–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	mist
4......	LS–Pb 1½–2–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	LS–Pb 1½–2–50	penetration

Comparison of the effects of mist and penetration methods of applying spray materials, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Ben Davis..	1	15.46	1.74	7.75
	2	10.34	1.40	22.59
	3	4.94	1.29	1.60
	4	11.76	2.47	14.36
Winesap...	1	14.08	2.07	6.80
	2	11.72	1.83	20.13
	3	8.94	2.44	2.92
	4	11.32	1.18	14.53
Jonathan..	1	13.74	2.00	9.23
	2	5.20	1.37	22.32
	3	4.88	1.38	1.62
	4	11.66	2.50	14.05
Combined varieties...	1	14.34	1.96	7.91
	2	9.24	1.58	21.41
	3	6.69	1.83	2.19
	4	11.53	1.91	14.33

At Nemaha (table 49), mist nozzles were used for each spray on plats 1 and 3 except the petal-fall application, when Bordeaux nozzles were used. Practically no difference was found except in the amount of spray injury, which was considerably more on the penetration plats in the case of both Bordeaux and lime sulphur than on the mist plats.

TABLE 50—*Lincoln spray schedule*

	Cluster-bud	Petal-fall	3-weeks	Second-brood	
Plat 1......	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	mist
2......	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	Bx–Pb 3–4–2–50	penetration

Comparison of the effects of mist and penetration methods of applying spray materials, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Ben Davis Jonathan	1	21.37	.65	21.21
	2	20.10	.57	41.60
	check	39.58	34.85	....

At Lincoln (table 50), all the applications on plat 1 were made with mist nozzles and all on plat 2 with Bordeaux nozzles. Again no difference was found except in the amount of spray injury, which was 20 per cent greater on the penetration plat.

TABLE 51—*Beatrice spray schedule*

	Cluster-bud	Petal-fall	25-days	Second-brood	
Plat 1......	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	Pb–LS 2–1.008	mist
2......	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	Pb–LS 2–1.008	penetration

Comparison of the effects of the mist and penetration methods of spraying, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Ben Davis Mo. Pippin	1	47.63	.53	3.35
	2	47.90	.31	8.39
	check	77.16	24.32	....

At Beatrice (table 51), mist nozzles were used thruout on plat 1. The only difference between the two plats was in the amount of spray injury. There was 5 per cent more spray injury on the penetration than on the mist plat.

TABLE 52—*Lincoln spray schedule*

	Cluster-bud	Petal-fall	25-days	35-days	2d-brood	
Plat 1...	Bx–Pb 4–6–2–50	Pb–LS 2–1.008	Bx–Pb 3–4–2–50	....	Bx–Pb 3–4–2–50	mist
2...	Bx–Pb 4–6–2–50	Pb–LS 2–1.008	Bx–Pb 3–4–2–50	....	Bx–Pb 3–4–2–50	penetration
3...	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	....	Pb–LS 2–1.008	mist
4...	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	....	Pb–LS 2–1.008	penetration

Comparison of the effects of the mist and penetration methods of spraying, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Ben Davis Winesap...	1	49.69	.07	4.56
	2	48.39	.17	4.86
	3	53.52	.14	4.97
	4	53.85	.15	5.51

At Lincoln (table 52), mist nozzles were used on plats 1 and 3 except for the petal-fall spray, when Bordeaux nozzles were used. Bordeaux nozzles were used thruout on plats 2 and 4. This table furnishes no evidence in favor of either method.

TABLE 53—*Seward spray schedule*

	Cluster-bud	Petal-fall	3-weeks	Second-brood	
Plat 1......	Bx–Pb 4–6–2–50	Pb–LS 2–1.008	Pb–LS 2–1.008	Bx–Pb 3–4–2–50	mist
2......	Bx–Pb 4–6–2–50	Pb–LS 2–1.008	Pb–LS 2–1.008	Bx–Pb 3–4–2–50	penetration
3......	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	Pb–LS 2–1.008	mist
4......	Pb–LS 2–1.009	Pb–LS 2–1.008	Pb–LS 2–1.008	Pb–LS 2–1.008	penetration

Comparison of the effects of mist and penetration methods of applying spray materials, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Ben Davis Winesap...	1	23.10	2.42	1.61
	2	24.26	4.25	3.16
	3	27.73	1.99	2.06
	4	23.41	1.54	2.74
	check	84.50	25.23	....

At Seward (table 53), no evidence could be found favoring either method of spraying. Poor pressure was maintained thruout, which may account for the lack of difference in the amount of injury. Bordeaux nozzles were used for the petal-fall application on plats 1 and 3. Mist nozzles were used for the remaining applications. Bordeaux nozzles were used thruout on plats 2 and 4.

TABLE 54—*Beatrice spray schedule*

	Cluster-bud	Petal-fall	14-days	Second-brood	
Plat 1......	Pb–LS 1.5–1.01	Pb–LS 1.5–1.009	Pb–LS 1.5–1.009	Pb–LS 1.5–1.009	mist
2......	Pb–LS 1.5–1.01	Pb–LS 1.5–1.009	Pb–LS 1.5–1.009	Pb–LS 1.5–1.009	penetration

Comparison of the effects of mist and penetration methods of spraying, by percentages

Variety	Plat	Insect injury	Fungous injury	Spray injury
Mo. Pippin	1	5.92	32.48	3.31
	2	5.73	22.84	11.21
	check	33.54	210.60	....
Ben Davis	1	6.11	28.19	5.04
	2	5.89	23.29	10.54
	check	44.61	188.15	....
Mo. Pippin Ben Davis	1	6.00	30.66	4.05
	2	5.79	23.00	10.97
	check	39.46	198.60	....

At Beatrice (table 54), there was a slight difference in favor of the penetration method of spraying as shown by the amount of fungous infection controlled, but this was balanced by the greater

amount of spray injury caused by this method. Plat 1 was sprayed with mist nozzles at each application and plat 2 with Bordeaux nozzles.

SUMMARY

The evidence presented by the data on codling moth control and that shown in the foregoing tables indicate that more injury is done by using solid-stream nozzles than by using those of the hollow-stream type, while there is practically no more efficiency secured. Even for the petal-fall spray nothing is gained by using the Bordeaux type of nozzle. The filling of all calyx cups and the thoro covering of all parts of the tree, fruit, and foliage with the least expenditure of labor and material and with a minimum amount of injury to the fruit constitutes efficiency in spraying. Coarse mist nozzles operating under 225 to 250 pounds pressure will throw a penetrating heavy mist several feet thru the foliage of an ordinary tree and will fill the calyx cups as readily and cover all parts of the foliage more evenly and thoroly than will the Bordeaux type of nozzle.

To prevent injury, the material should be applied evenly, so that the liquid will not collect in large drops or run off. There is less danger of missing any part of the tree, and the fruit is not so liable to be russeted by the hard particles in the spray, when applied in this way.

The relative costs of the two methods of spraying will be discussed later.

CUMULATIVE EFFECTS OF SPRAYING

The argument is often advanced that it does not pay to spray when a crop is not expected or when the insect infestation or the fungous infection is light. This is a fallacy. The orchardist cannot afford to neglect spraying just because there is no promise of immediate returns. Spraying will more than pay expenses in the benefit to the following year's crop. At Florence in 1913 only a part of a 30-acre orchard was sprayed. The whole orchard was sprayed in 1914 and 1915, but at harvest time in 1915 the effect of the thoro spraying received by but a part of the trees in 1913 was still decidedly noticeable. The effects were so evident that the packers, who were not acquainted with the facts of the case, found a decided difference in the grades of fruit from the two parts of the orchard.

The following tables also indicate that the cumulative effects make spraying decidedly worth while even in an "off year."

TABLE 55—*Cumulative effect of spraying (by percentages)*

Variety	Plat	Insect injury	Fungous injury	
Mo. Pippin	1	5.73	22.84	....
	2	12.83	57.32	....
	check	33.54	210.58	....

Both plats in table 55 were sprayed in 1915, but only plat 1 received any spray in 1914. The plats were only two rows apart in the same orchard. In recording fungous injury, 210 per cent was secured by adding together the apples affected by scab, blotch, and sooty blotch.

The foregoing data, while not exhaustive, serve to indicate the importance of continued effort in insect and disease control.

TABLE 56—*Cumulative effect of spraying (by percentages)*

Variety	Plat	Insect injury	Fungous injury	
Jonathan....	1	9.79	30.37	....
Ben Davis...	1	19.65	50.34	....
	total	11.15	33.12	....
Ben Davis...	2	110.42	192.02	....
Jonathan.....	2	77.44	99.95	....
	total	94.62	147.90	....

At Omaha (table 56), neither plat was sprayed in 1915, the year in which the data were taken. Plat 1 was sprayed for five consecutive years prior to 1915. Plat 2 has never been sprayed. The plats were situated one-half mile apart.

COST OF SPRAYING

Accurate accounts were kept of all labor and materials used in spraying thruout the three seasons' work. In computing costs of spraying, averages were made for each type of machine, for all Bordeaux schedules, for lime sulphur schedules, and for the mist and penetration schedules. In computing the cost of lime sulphur the $1\frac{1}{2}$–2–50 formula was used, the cost of poison being included. In computing the cost of Bordeaux and arsenate of lead the 3–4–2–50 formula was used.

The following tables show the comparative efficiency of the general types of spraying machinery as well as the cost of the spraying.

TABLE 57—*Comparative cost of spraying with machines of various capacities*

No. of spray	No. leads of hose	Kind and No. of nozzles	Pressure	Distance to haul	No. trees sprayed per day	Amount to tree in gals.	COST PER TREE				TOTAL
							LABOR		MATERIAL		
							Men	Teams	Fungicide	Insecticide	
A.—50-gallon barrel pump. 2- to 3-gallons-per-minute capacity. Two men and one team used											
1	1	1 large mist	160	¼ mile	125	4	.032	.012	.0144	.0112	.0696
2	1	1 “ “	160	¼ “	100	6.5	.04	.015	.0234	.0182	.0966
3	1	1 “ “	160	¼ “	140	4.5	.0285	.0107	.0162	.0126	.068
4	1	1 “ “	160	¼ “	130	4.2	.0307	.0115	.0151	.01176	.06906
										Total cost	.30326
B.—Double acting horizontal power pump. 3- to 4-gallons-per-minute capacity. 100-gallon tank. Three men and one team used											
1	1	2 mist	135	⅛ mile	200	5	.03	.0075	.018	.014	.0695
2	1	2 “	220	⅛ “	150	7	.04	.01	.0252	.0196	.0948
3	1	2 “	200	⅛ “	200	4	.03	.0075	.0144	.0112	.0631
4	1	2 “	200	⅛ “	200	4	.03	.0075	.0144	.0112	.0631
										Total cost	.2995
C.—One-man duplex power pump. 3- to 4-gallons-per-minute capacity. 150-gallon tank. Two men and one team used											
1	1	2 mist	150	⅛ mile	210	4.5	.019	.0071	.016	.0126	.0547
2	1	2 “	150	⅛ “	200	6.5	.02	.0075	.0234	.0182	.0691
3	1	2 “	150	⅛ “	220	5	.018	.0068	.018	.014	.0568
4	1	2 “	150	⅛ “	230	4.7	.0173	.0065	.0169	.0131	.0538
										Total cost	.2360
D.—Horizontal power pump. 8- to 10-gallons-per-minute capacity. 200-gallon tank. Three men and one team used											
1	2	4 mist	225–250	⅛ mile	320	4.5	.0187	.00468	.0162	.0126	.05218
2	2	4 Bx.	225–250	⅛ “	320	7	.0187	.00468	.0252	.0196	.06818
3	2	4 mist	225–250	⅛ “	266	5.5	.0225	.00563	.0198	.0154	.06333
4	2	4 “	225–250	⅛ “	266	6	.0225	.00563	.0216	.0168	.06653
										Total cost	.25022

TABLE 58—*Comparison of the mist and penetration methods of spraying, using lime sulphur*
Power pump. 10- to 12-gallons-per-minute capacity. Three men and one team used

No. of spray	No. leads of hose	Kind and No. of nozzles	Pressure	Distance to haul	No. trees sprayed per day	Amount to tree in gals.	COST PER TREE: LABOR: Men	COST PER TREE: LABOR: Teams	COST PER TREE: MATERIAL: Fungicide	COST PER TREE: MATERIAL: Insecticide	TOTAL
A											
1	2	4 mist	225	1/3 mile	533	3.0	.0113	.00281	.0108	.0084	.03331
2	2	4 "	250	1/3 "	355	7.5	.014	.00422	.0270	.021	.06622
3	2	4 "	225	1/3 "	355	4.5	.014	.00422	.0162	.0126	.04702
4	2	4 "	220	1/3 "	400	4.0	.015	.00375	.0144	.0112	.04435
										Total cost	.1909
B											
1	2	4 mist	225	1/4 mile	500	4.0	.012	.003	.0144	.0112	.0406
2	2	4 "	250	1/4 "	325	8.5	.0184	.0046	.0306	.0238	.0774
3	2	4 "	200	1/4 "	400	5.0	.015	.00375	.018	.014	.05075
4	2	4 "	200	1/4 "	400	5.0	.015	.00375	.018	.014	.05075
										Total cost	.21950
C											
1	2	4 Bx.	225	1/8 mile	320	6.5	.0187	.00468	.0234	.0182	.06498
2	2	4 "	250	1/8 "	220	9.5	.0272	.00680	.0342	.0266	.0948
3	2	4 "	225	1/8 "	320	7.6	.0187	.00468	.0273	.02128	.07196
4	2	4 "	225	1/8 "	266	7.5	.0225	.00563	.0270	.021	.0761
										Total cost	.30784
D											
1	2	4 Bx.	225	1/8 mile	400	5.0	.015	.00375	.018	.014	.05079
2	2	4 "	250	1/8 "	250	8.0	.0240	.00600	.0288	.0224	.08120
3	2	4 "	225	1/8 "	350	6.0	.0171	.00427	.0216	.0168	.06977
4	2	4 "	225	1/8 "	350	6.0	.0171	.00427	.0216	.0168	.06977
										Total cost	.27149

TABLE 59—*Comparison of the mist and penetration methods of spraying, using Bordeaux*

Power pump. 10- to 12-gallons-per-minute capacity. Three men and one team used

No. of spray	No. leads of hose	Kind and No. of nozzles	Pressure	Distance to haul	No. trees sprayed per day	Amount to tree in gals.	COST PER TREE				TOTAL
							LABOR		MATERIAL		
							Men	Teams	Fungicide	Insecticide	
					A						
1	2	4 mist	225	⅓ mile	466	3	.0128	.0032	.012	.0084	.0364
2	2	4 "	250	⅓ "	350	5.9	.0171	.0042	.0236	.01652	.06142
3	2	4 "	225	⅓ "	311	4.5	.0192	.0048	.018	.0126	.0546
4	2	4 "	220	⅓ "	350	4	.0171	.0042	.016	.0112	.0485
										Total cost	.20092
					B						
1	2	4 mist	225	¼ mile	450	4	.0133	.0033	.016	.0112	.0438
2	2	4 "	250	¼ "	325	8.5	.0187	.0046	.034	.0238	.0811
3	2	4 "	200	¼ "	360	5	.0166	.0041	.020	.0140	.0547
4	2	4 "	200	¼ "	360	5	.0166	.0041	.020	.0140	.0547
										Total cost	.2343
					C						
1	2	4 Bx.	225	⅛ mile	320	6.2	.0187	.00468	.0248	.01736	.06554
2	2	4 "	250	⅛ "	310	11	.0193	.0048	.044	.0308	.0989
3	2	4 "	225	⅛ "	300	8	.02	.005	.032	.0224	.0794
4	2	4 "	225	⅛ "	275	8	.0218	.0054	.032	.0224	.0816
										Total cost	.32544
					D						
1	2	4 Bx.	225	⅛ mile	360	5	.0166	.0041	.020	.0140	.0547
2	2	4 "	250	⅛ "	300	8	.02	.005	.032	.0224	.0794
3	2	4 "	225	⅛ "	300	6	.02	.005	.024	.0168	.0658
4	2	4 "	225	⅛ "	300	6	.02	.005	.024	.0168	.0658
										Total cost	.2657

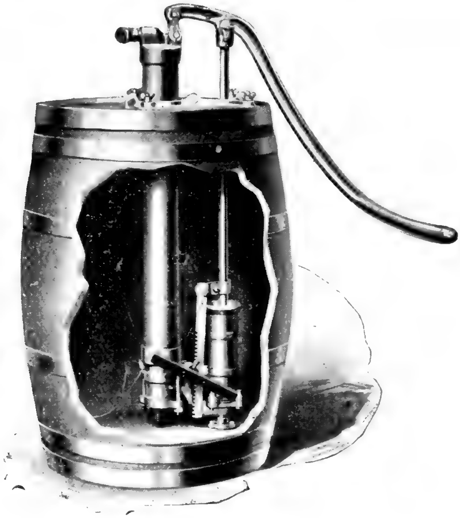


Fig. 18—A good type of barrel pump

Table 57 A shows the average cost of spraying with a barrel pump similar to fig. 18. An outfit of this kind is efficient for an orchard of 300 trees or less, considering 20 to 24-year-old trees as an average.

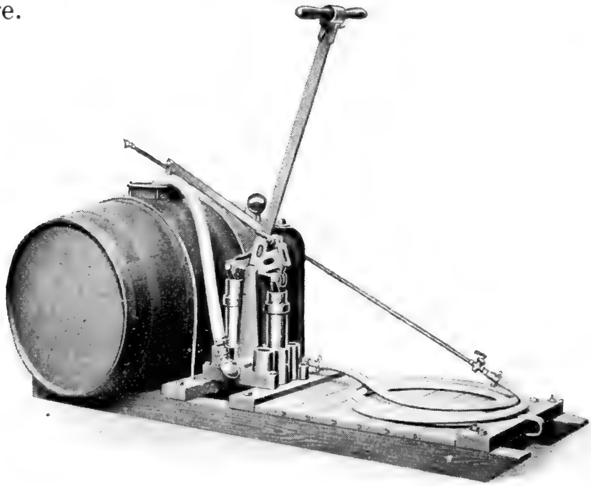


Fig. 19—A hand pump affording greater pressure than the pump shown in Figure 18

Table 57 B shows the average cost of spraying with the larger capacity hand pumps similar to fig. 19. A machine of this capacity is efficient for an orchard of 300 to 400 trees.

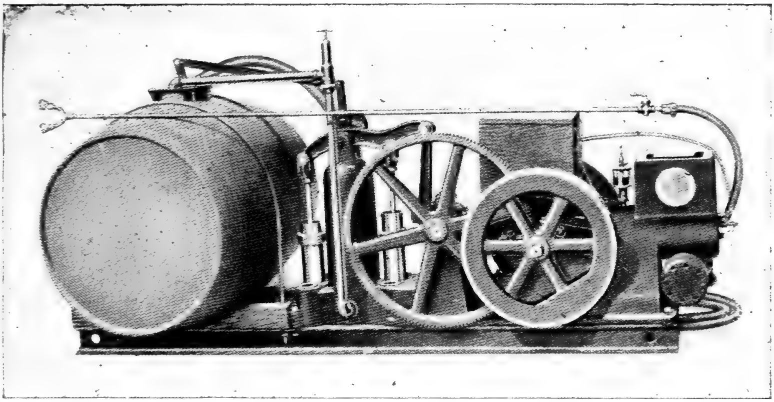


Fig. 20—A small power outfit which may be operated by one man alone

Table 57 C shows the average cost of spraying with the one-man type of power sprayer similar to fig. 20. A machine of this capacity is efficient for orchards of from 400 to 600 trees.

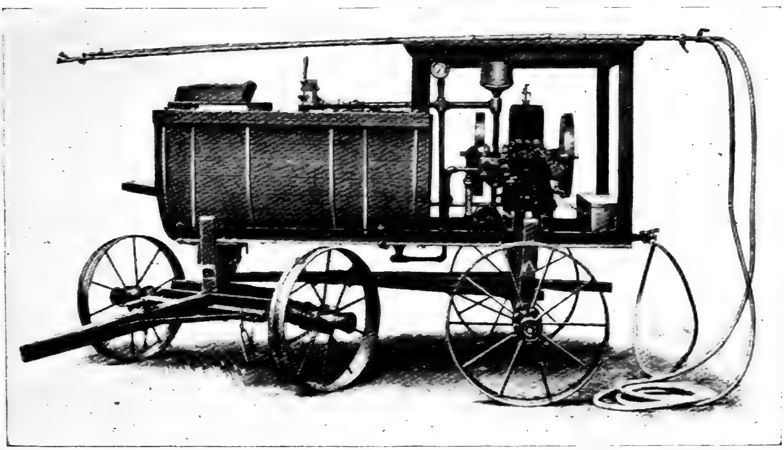


Fig. 21—Power outfit of the horizontal pump type; 8- to 10-gallons-per-minute capacity

Table 57 D shows the average cost of spraying with a type of machine similar to that shown in figs. 21 and 22. A machine of this capacity is efficient for an orchard of 600 to 1,000 trees.

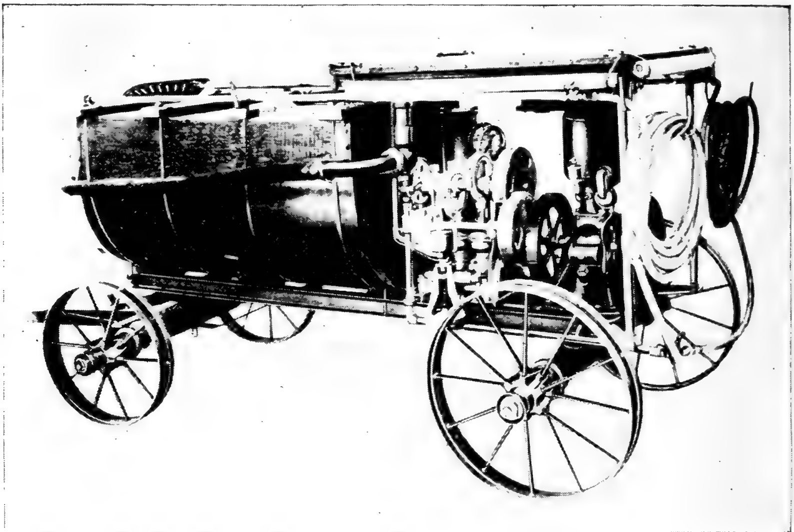


Fig. 22—A Duplex power outfit of the same capacity as the machine shown in figure 21

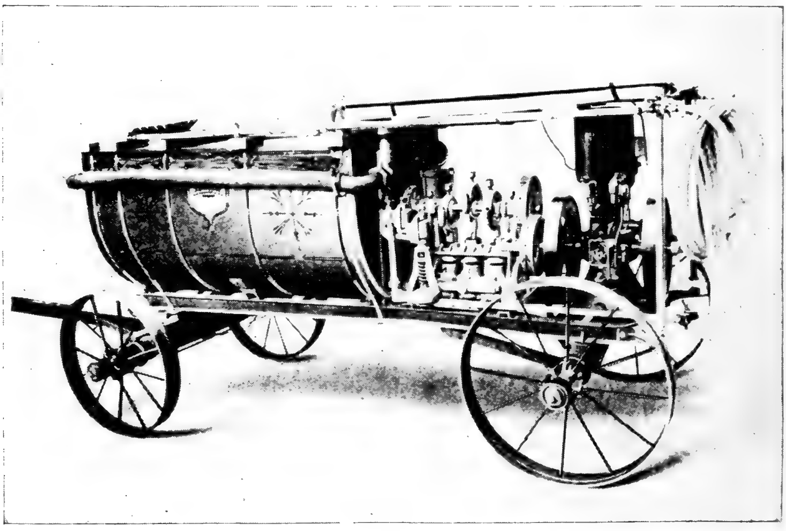


Fig. 23—A Triplex machine of 10- to 12-gallons-per-minute capacity

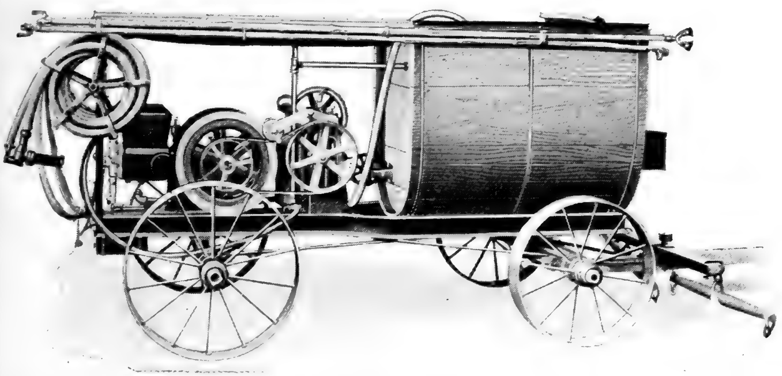


Fig. 24—A Triplex machine of the same capacity as the one shown in figure 23

Tables 58 and 59 show the cost of spraying with the large capacity machines similar to fig. 23 or similar to fig. 24, but of larger capacity. Machines of this capacity are efficient for 1,000 to 2,000 trees.

Efficient service cannot be secured where the capacity of the machine is too small to spray the orchard in five or six full days of good weather. The capacity of the machine needed may be determined by the length of time the calyx cups remain open. This is usually 7 to 10 days. A single machine may be used to spray more than this if the varieties are so arranged that one part of the orchard comes into bloom later than another; but with our standard varieties of apples, not more than two or three days can be gained in this way. It is little wonder that the fruit grower who sprays (?) 50 to 100 acres of orchard with one machine fails to get results.

The cost of spraying with lime sulphur is shown in table 58. This table also shows the comparative cost of the mist and the penetration methods of spraying. The penetration method is more expensive from the fact that more time is consumed in applying the spray and for the reason that more material is used. That this excess is wasted is shown by the fact that the efficiency was no higher than when the spray was applied as a mist. This superfluous amount of material may account for a part of the excessive spray injury caused by the penetration method of spraying.

Table 59 shows the cost of spraying with Bordeaux as well as a comparison of the mist and penetration methods of spraying.

Little difference is shown between the actual cost of spraying with Bordeaux and with lime sulphur as indicated by the tables. The cost of material for the former is somewhat less; but the additional labor of making it brings the cost up equal to that of lime sulphur.

RESULTS OF SPRAYING BASED ON COMMERCIAL RETURNS

It is impossible to make a fair comparison of commercial returns from spraying in widely separated orchards, in the treatment of which the only thing in common is spraying. For instance, the percentage of fruit free from insect or fungous injury may be higher in a sod orchard than in an orchard under cultivation, but when the fruit is graded the returns from the cultivated orchards are larger because the individual apples are larger. Again, a well-pruned orchard may show higher returns when the fruit is graded than an unpruned orchard in spite of the fact that the number of sound apples in the latter is much greater. As in the first instance, the size of the individual apples is the determining factor. In table 59, commercial grades of the sprayed plats are compared with commercial grades from check trees in the same orchard. No attempt is made to compare the results from the different orchards.

TABLE 60—*Commercial grades of picked fruit from plats showing best results for the different seasons*

Location	Plat	Treatment	Application: Cluster-bud	Petal-fall	7-days	14-days	21-days	35-days	2d-brood	3d-brood	Variety	Percentage grades of picked apples: Av'ge fruit to tree in bu.	No. 1	No. 2	No. 3	Culls	Value
1913																	
Wymore..	1	LS-Pb 1.5-2-50....	1	2	....	....	....	....	....	....	Ben Davis Mo. Pippin	15.25	....	[2]72.13	19.67	8.19	......
		[1]Bx-Pb 3-4-2-50....	......	......	....	....	3	....	4	....		......	....	[2]22.22	......	......	......
	check	......	......	......	....	....	....	....	....	....		6.75	....	......	33.33	14.44	......
1914																	
Beatrice..	2	LS-Pb 1.009-2-50..	......	2	....	....	....	....	....	....	Ben Davis Mo. Pippin	9.	....	......	14.01	7.7	......
		[1]Bx-Pb 3-4-2-50....	1	......	....	....	3	....	4	....		......	....	[2]78.28	......	......	......
	check	......	......	......	....	....	....	....	....	....		.75	....	......	38.5	61.5	......
Lincoln...	3	LS-Pb 1.009-2-50..	1	2	....	....	3	....	4	5	Ben Davis Winesap Jonathan	17.00	81.9	......	12	6.1	......
	check	......	......	......	....	....	....	....	....	....		4.25	....	......	27.6	72.4	......
1915																	
Beatrice..	4	LS-Pb 1.009-2.5-50.	1	2	....	3	....	....	....	....	Ben Davis Mo. Pippin	10.3	53.49	34.72	10	1.79	......
		[1]Bx-Pb 3-4-2.5-50..	......	......	....	....	....	4	5	....		......	......	......	......	......	......
	check	......	......	......	....	....	....	....	....	....		1.75	3.33	4.44	8.889	83.33	......
Omaha...	5	LS-Pb 1.009-2.5-50.	1	2	....	....	3	....	4	....	Ben Davis Jonathan	21.7	55.2	33.3	10.41	1.04	......
	check	......	......	......	....	....	....	....	....	....		6.8	16.00	40.00	38.86	5.14	......
Lincoln...	6	HBLS-Pb 1.009-2.5-50	1	2	....	....	3	....	4	....	Ben Davis Winesap Jonathan	19.2	....	[2]37.55	11.63	.82	......
	check	......	......	......	....	....	....	....	....	....		6.5	....	14.57	52.98	32.45	......

[1]Blotch was present in these orchards, consequently lime sulphur did not give as good results as where Bordeaux was used the latter part of the season.

[2]Grades Nos. 1 and 2 were combined.

In computing the value, the actual selling price of the fruit was taken. The culls were not considered since they were not sold. The net gain per tree from spraying these plats may be found as follows:

Plat 1—	Total value of fruit	$12.05
	Value of fruit on check plat	2.28
	Difference	9.77
	Cost of spraying	.29
	Net gain from spraying	9.48
Plat 2—	Total value of fruit	7.47
	Value of fruit on check	.10
	Difference	7.37
	Cost of spraying	.25
	Net gain from spraying	7.12
Plat 3—	Total value of fruit	14.63
	Value of fruit on check	.40
	Difference	14.23
	Cost of spraying	.26
	Net returns from spraying	13.97
Plat 4—	Total value of fruit	10.59
	Value of fruit on check	.21
	Difference	10.38
	Cost of spraying	.24
	Net gain from spraying	10.14
Plat 5—	Total value of fruit	26.31
	Value of fruit on check	5.66
	Difference	20.65
	Cost of spraying	.25
	Net gain from spraying	20.40
Plat 6—	Total value of fruit	17.55
	Value of fruit on check	2.14
	Difference	15.41
	Cost of spraying	.26
	Net gain from spraying	14.15

The above yields no doubt appear high, and would be high were we considering the average of the whole orchard, but it must be remembered that the trees under observation were chosen because of their uniformly good state of health, shape, size, and fruitfulness. Considering all the trees in the various orchards, the net gain per tree on the sprayed portions was approximately one-half the amount shown above.

GENERAL SUMMARY AND RECOMMENDATIONS

Three sprays are required during a normal season to control an ordinary infestation of codling moth. The first spray should be applied immediately after two-thirds to three-fourths of the petals have fallen. The spray should be applied as a coarse mist, directly against the face of the open calyces. In order to apply the spray properly the greater part of the spraying should

be done from the tower. A good arrangement, where the trees are large, if a large capacity machine is used, is for two men to work from the tower and one from the ground. The material should be applied downward with a stroking motion of the rod, beginning at the extreme tip of the branches and following down to the trunk. In this way there is a mimimum danger of missing any of the calyces. More material is needed for this application than for any other. The pressure should be 225 to 250 pounds. The next spray should be applied about three weeks later and should consist of a fine mist. The paramount object of this application is to cover thoroly all growing parts of the tree. The material should be directed both above and below with long stroking motions, beginning at the tips of the branches. The exact time for applying this spray is immediately after the moths begin to deposit their eggs, and may be determined as indicated on page 12.

The third spray for codling moth should be applied immediately after the eggs, from which the second-brood larvæ hatch, are laid and should be applied in the same manner as the preceding spray.

In abnormal seasons, like that of 1914, when owing to favorable conditions the moths emerge early and multiply rapidly, a third-brood spray is necessary.

Practically no difference was found in the effectiveness of any of the standard brands of arsenate of lead.

Two pounds of arsenate of lead "paste" or $1\frac{1}{4}$ pounds of arsenate of lead powder has been found to be as efficient as more.

In spraying for the control of the plum curculio, the work must be done early in the season. It was found necessary to apply one spray before the flowers open. The time for the remaining sprays corresponds so closely to the first two codling moth sprays that the schedule for that insect may be adopted. It has been shown, however, that a spray as late as the second-brood codling moth application is as a rule of little value in controlling the curculio.

In an average season, in orchards where clean culture and thoro spraying have not greatly reduced the infection three sprays are necessary to control the primary infection of apple scab. The first spray should be applied before the blossoms open and may be combined with the first spray for plum curculio. The next two sprays correspond so closely with the first and second sprays for codling moth, and the second and third for curculio that the poison and fungicides may be combined. In case of a heavy secondary infection, such as occurred in 1915, a later spray, corresponding so closely to the time of the second-brood codling moth application that it may be combined with it, is necessary.

The first spray for the control of blotch should be applied about three weeks after the petals fall and may be combined with the second codling moth application. In cases of severe infection another application may be necessary 15 to 20 days later.

Rust and sooty blotch are usually controlled incidentally.

Practically no difference has been found in the efficiency of Bordeaux and lime sulphur in controlling fungous diseases, except in the case of apple blotch. For controlling this disease Bordeaux is much more efficient than lime sulphur. On the other hand it is also much more liable to injure the fruit when used early in the season. In fact more or less danger accompanies its use at any time.

No way of eliminating Bordeaux injury has been found. Lime used in excess is of no value. The application of milk of lime, following rains, to trees which have been sprayed with Bordeaux does not lessen the injury to any appreciable extent.

It was found practicable to interchange Bordeaux and lime sulphur sprays in a schedule, so as to afford a maximum amount of control with a minimum amount of injury. Bordeaux may be used with little injury for the first or cluster-bud spray, and as a rule not very much injury accompanies its use three weeks after the petals fall or later, unless wet weather follows its application. Bordeaux should be used for the 3-weeks spray where blotch infection is heavy, but in case of wet weather it would be best to use lime sulphur instead and as soon as a period of fair weather arrives apply Bordeaux. Where the 35-days spray is applied for blotch, Bordeaux should be used.

Home boiled lime sulphur has been found as efficient a fungicide as the ordinary commercial product. However, only the clear liquid should be used, as the coarse particles in the sludge may, when thrown with force against the tender skin of the fruit, cause russeting.

Among the various new fungicides which were tried, none were found to be in any way superior to the two standard fungicides now in use. Bordeaux arsenate, Pyrox, and tuber tonic proved effective in controlling fungi, but all caused considerable damage to fruit and foliage, and are more expensive than Bordeaux.

Soluble sulphur and atomic sulphur proved effective in controlling apple scab but both did too much damage to fruit and foliage to warrant their use in their present form. Both would be desirable sprays could this disagreeable feature be eliminated.

Spray applied with hollow-stream nozzles was found fully as effective as when applied with the solid-stream type. More spray injury accompanies the use of the latter, and the unavoidable waste of material makes their use more expensive.

The results of the last three seasons indicate that while it is sometimes possible to omit either the fungicide or the insecticide in the first spray, or to omit the first spray altogether, without suffering serious loss, it is never safe to do so. It is more hazardous to omit the fungicide than the insecticide. The omission of the fungicide in 1915 would have been almost disastrous in the average orchard, and the omission of the insecticide would have meant the loss of several bushels of fruit out of every hundred bushels.

There is no doubt that the beneficial effects of spraying are noticeable for more than a single season and that thoro spraying for a number of years will greatly lessen insect infestation and disease infection.

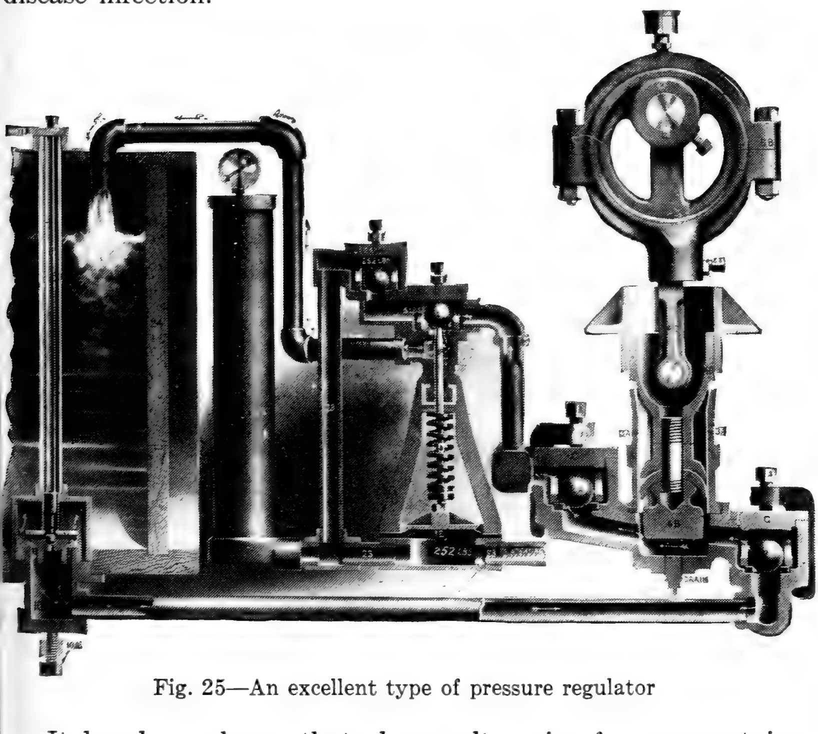


Fig. 25—An excellent type of pressure regulator

It has been shown that clean culture is of paramount importance in controlling plum curculio and apple scab.

The capacity of the spraying machine must be gauged by the size of the orchard and the length of time available for applying the petal-fall spray. The time from the falling of the petals to

the complete closing of the calyces is usually seven to ten days. It is not safe to attempt to spray more trees than can be covered in five or six full days with one machine.

Power machines are the most satisfactory where the orchard is large enough to warrant their use, tho not necessarily more efficient than a good type of hand pump outfit when the latter is properly used. With any outfit the nozzle capacity must be regulated to fit the capacity of the pump. No outfit will do good work when the pump is unable to supply the liquid fast enough to maintain a good pressure. It makes little difference whether a double acting horizontal pump or an upright duplex or triplex pump is used if the capacity is large enough and it is well made, provided plenty of power is supplied to operate it at full capacity and the outfit is not too heavy. The outfit shown in fig. 21 is of the horizontal type and the one shown in figs. 23 and 24 belongs to the upright plunger type. However excellent in all other ways, an outfit is not dependable unless it has a good pressure regulator. One of the best pressure regulators is shown in detail in fig. 25.

It must be remembered that efficiency in spraying is secured only by doing the work thoroly and at a time that will prevent infestation and infection. Protection by spraying is preventive rather than curative. A spray applied at the wrong time is little better than no spray. Spraying in a half-hearted way is often worse than no spray. It costs money but does no good. It is cheaper to buy efficient machines than to "kill time tinkering" with a poor machine.

(10-24-'16—4 M)

RESEARCH BULLETIN NO. 11

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

RELATION OF SIZE OF SEED AND SPROUT VALUE TO THE YIELD OF SMALL GRAIN CROPS

By T. A. KIESSELBACH and C. A. HELM

ACCEPTED FOR PUBLICATION, APRIL, 1917
DISTRIBUTED DECEMBER 1, 1917

LINCOLN, NEBRASKA
U. S. A.

[1]Resigned
[2]Detailed from Office of Dry Land Agriculture, United States Department of Agriculture, Washington, D. C.
[3]Granted leave of absence for military service
[4]Granted leave of absence

CONTENTS

SUMMARY

1. In a study of the reserve food content of small grain seeds, the term "sprout value" has been assigned to the moisture-free weight of the maximum plant growth derived from the seed when planted and grown in a nonnutritive quartz medium and in absolute darkness. Under these conditions, no photosynthesis nor intake of soil solutes is possible, and the moisture-free substance of the seedling is derived from the reserve food material of the seed.

2. As an average for all the grades of wheat seed tested in 1913 and 1914, the total sprout value of the seed equaled 54.2 per cent and 46.3 per cent of the weight of seed planted in 1913 and 1914 respectively. In other words, 50.2 per cent of the seed substance was recovered in the sprout as an average for the two years. The total loss of substance not recovered in either the sprout or the inert seed residue averaged 38.5 per cent during 1913 and 1914.

3. As an average for all tests during two years, 1913 and 1914, the ratios for the moisture-free weight of unselected seed to the large and small seed were respectively 100:127 and 100:85, while the ratios for the total sprout value were 100:123 and 100:88 respectively. This indicates a rather close relationship between the size of seed and its sprout value.

4. As an average for three tests, the carbon dioxide liberated from wheat seeds by respiration during fourteen days' growth in the dark in a nonnutritive medium amounted to 39.22 per cent of the original moisture-free weight of the seed. The sprout value of the same seed equaled 47.28 per cent of the original dry matter of the seed.

5. Very small or shrunken wheat seeds are at a marked disadvantage in comparison with large seeds, when planted at the unusual depth of 5 or 6 inches.

6. The separation of the mature crop of wheat, grown at the normal rate of planting, into individual plants was accompanied by an average error of 7.6 per cent. For this reason, the number of individual plants surviving from large and small seeds at harvest was not determined in these experiments.

7. The relative production of large and small seeds of wheat was determined when planted alone, and when grown in competition by alternating the seeds in rows planted at the normal field rate. The small seeds weighed 66 per cent as much as the large seeds and had a sprout value 68 per cent as large. The germinations of the two grades were practically equal.

When planted alone, the small seeds produced 6 per cent fewer culms and in competition 18 per cent fewer culms than the large. The yield of grain was 11 per cent smaller for the small seeds planted alone, and 24 per cent smaller in competition than for the large seeds. The straw yield was 6 per cent smaller for the small seed alone, and 25 per cent smaller in competition than for the large seed. The total plant yield was 7 per cent smaller for the small seed planted alone and 25 per cent smaller in competition than for the large seed.

8. Competition between alternating plants of two wheat varieties may be very marked. Thus, in 1914, when grown at the normal rates of planting, the yields of grain, straw, total crop, and number of culms for Big Frame winter wheat were respectively 90, 88, 89, and 80 per cent as large as for the Turkey Red. But when grown in competition, the Big Frame yields were respectively only 55, 70, 67, and 68 per cent as large as for the Turkey Red. The relative competitive qualities of these two varieties were reversed in 1915, due to a great difference in climatic conditions. However, the effect of variety competition is very apparent. Planted alone, the yields of grain, straw, total crop, and number of culms for Big Frame winter wheat were respectively 82, 105, 99, and 94 per cent as large as for the Turkey Red. In competition, these Big Frame yields were respectively 120, 128, 125, and 117 per cent as large as for the Turkey Red.

Similar (tho not quite so striking) results were obtained for spring wheat. These investigations suggest that competition may play a very important role in the natural improvement of cereal crops.

9. In a 2-year yield test of unselected, large, and small seeds of two winter wheat varieties, the average relative seed weights were 100, 134.6, and 86.9, with corresponding sprout values of 100, 133, and 92.3. The grain yield of the large seed was 2.3 per cent superior to the unselected seed, while the grain yield from the small seed was 3.1 per cent inferior.

The 2-year average relative weights of unselected, large, and small seeds of two spring wheat varieties were respectively 100, 117.3, and 78.4, while the corresponding relative sprout values were 100, 110.4, and 71.8. With the spring wheat, the large seed outyielded the unselected for grain 11.8 per cent, while the grain yield of the small seed was 7.7 per cent inferior to the unselected seed.

In these tests, the seeds were planted in equal numbers at a normal rate for the large seeds.

10. When two grades each of spring wheat and oats were space-planted to permit maximum plant development, the small

seed compared with the large produced 80 per cent as many culms per plant, 72 per cent as high grain yield, 77 per cent as great straw yield, and 77 per cent as great total yield. In these tests, the small seeds planted averaged 52 per cent as heavy as the large.

11. In yield tests comparing large and small seeds planted both in equal numbers and equal weights at rates normal for the large seed, (1) the small seed of winter wheat yielded 4 per cent less than the large when planted in equal numbers, while the yields were equal when planted at equal weights; (2) the small seed of oats yielded 11 per cent less than the large when sown in equal numbers, and both yielded alike when equal weights of seed were used; (3) when sown in equal numbers, the small seed of spring wheat yielded 10 per cent less than the large seed, while it yielded only 1 per cent less when equal weights of seed were used; (4) as an average for all three crops, the small seed yielded $\frac{1}{3}$ of 1 per cent less than the large when equal weights of seed were sown, and 8 per cent less when planted in equal numbers.

12. During 12 years of continuous grading of Turkey Red and Big Frame winter wheat (by means of a fanning mill), the heaviest one-fourth seed has averaged 0.4 bushel more, while the lightest one-fourth seed has yielded 0.5 bushel less than the unselected seed.

13. As an average for 12 years' continuous use of the fanning mill, the heaviest and lightest one-fourth seed of Kherson oats have yielded respectively 0.83 bushel and 0.09 bushel more than the ungraded seed.

During 8 years' continuous use of the fanning mill, the lightest one-fourth seed of American Banner oats has yielded 1.43 bushels more than the heaviest one-fourth. In a 4-year period the ungraded seed was also compared and yielded 1.6 bushels less than the light seed, while the heavy seed yielded 3.67 bushels less than the lightest seed. In this variety, the selection of the light seed evidently resulted in securing the best adapted strains within the variety.

14. From a review of 60 experiments by various investigators, regarding the relative yields of grades of small grain seeds, the following principles are indicated:

(1) When space-planted to permit maximum development of the individual plants, a higher yield per plant is obtained from large than from small seed.

(2) When planted in equal numbers at a rate optimum for large seed, a lower yield is obtained from small than from large seed.

(3) When planted in equal weights, at a rate optimum for

the large seed, all three grades of seed—large, small, and unselected—yield equally.

(4) When distinct grades of light and heavy seeds (or large and small) are obtained from a fanning mill and planted in equal volumes as with a drill set at a uniform rate, slightly smaller yields are apt to result from the light seed. The difference in favor of large or heavy seed as compared with the original unselected seed is very slight, and probably so small as to have little practical significance.

The conclusion would seem justified that the practical use of the fanning mill in seed preparation consists largely in the removal of weed seeds and trash when present. If the seed is well cleaned at the threshing machine, little further is to be gained by fanning mill grading.

(5) Competition between plants from large and small seeds sown in a mixture acts to increase the relative yield from the large seeds. This suggests a natural elimination (within a mass variety) of poorly adapted types which produce unduly small or light weight seed.

RELATION OF SIZE OF SEED AND SPROUT VALUE TO THE YIELD OF SMALL GRAIN CROPS

T. A. KIESSELBACH AND C. A. HELM

RESERVE FOOD OF SEEDS

The food consumed by seed-producing crops in their initial growth during germination and prior to their independent existence originates in the reserve food stored either in the endosperm of the seed or in the cotyledons of the embryo plant within the seed. This reserve food is liberated by enzymatic action in the process of germination. When the roots have become established in the soil and the chlorophyll-bearing foliage has commenced development above the ground, the seedling is enabled to obtain necessary plant food material independent of reserve food within the seed. Under any conditions, the seedlings may continue to draw upon the store of reserve food until the supply has become exhausted and merely the nonavailable seed residue remains.

The actual amount of reserve food is indicated approximately by the difference in weight of the dry matter of the original seed planted and of the inert seed residues after the seedling has extracted all of the reserve food.

During growth, a portion of this reserve food enters into the plant substance of the seedling. Another portion is lost altogether from the plant during respiration in which carbon, oxygen, and hydrogen are liberated according to the following formula: $C_6H_{12}O_6 + 6\ O_2 = 6\ CO_2 + 6\ H_2O$. These two sources of loss in weight of seed substance upon germination comprise the chief disposition of the reserve food content of seeds. Other sources of loss are probably quite negligible.

Duggar (1911) states that "seeds which germinate rapidly may lose, under favorable conditions, one-third of their dry weight (by respiration) during a period of 10 days, which is an average of about 3 per cent a day."

That portion of the reserve food which enters into the seedling structure is quite accurately measurable, and for various grades of seeds is an index of the relative amounts of reserve food contents when planted under similar conditions. This portion is of prime importance in plant growth and represents the *sprout value* of the seeds.

A superior yielding power has frequently been attributed to the extra large seed. Since the seeds of any given crop commonly differ markedly in size, it is of importance from the standpoint of crop production to know the extent to which this difference in size may affect the yield of the crop produced. The following experiments have been conducted for the purpose of contributing further to the information upon this subject.

SPROUT VALUE OF DIFFERENT GRADES OF SEED

The sprout value is the moisture-free weight of the maximum plant growth derived from the seed when planted and grown in a nonnutritive quartz medium and in absolute darkness. Under these conditions no photosynthesis or intake of soil solutes is possible, and the moisture-free substance of the seedling is derived from the reserve food material of the seed.

In these experiments the sprout value of seeds was determined as follows: The seeds were grown to their maximum development in a pure quartz medium, in absolute darkness, at a temperature of 30° C., and watered only with distilled water. Maximum development was regarded to have taken place when further growth was not apparent and the seedling commenced deterioration. When this stage of development was reached, the entire seedling (including the roots) was very carefully washed from the sand in running water. All growth external to the seed was separated from the seed residue and the root growth and stem growth divided. The three portions were weighed separately after being rendered moisture-free by drying in an electric oven at 110° C. Since no substance may have been added to the seedlings either by intake of soil solutes or by photosynthesis, the weight of the root and stem growth together with the loss thru respiration, minus the inert seed residue, should represent the total available reserve food in the seeds tested.

RELATIVE SPROUT VALUES OF DIFFERENT GRADES OF SEED WHEAT

The relative sprout values of various grades of winter and spring wheat were determined according to the method previously described. The grades designated as large plump, small plump, large shrivelled, small shrivelled, large, small, and medium, were all selected by hand from original seed as secured from the threshing machine. In 1913, seed selected in the milk and dough stage from the growing crop were also included.

A chemical analysis was made of the various grades of wheat tested in 1913, and the composition is given in table 1. It is evident from the relative weights of the seed and the composition that distinct grades were employed.

TABLE 1—*Chemical analyses of wheat grades tested for sprout value (1913 crop)*[1]

Kind of seed tested	Average kernel weight	Ash	Nitrogen	Protein	Fat	Nitrogen-free extracts: Crude fiber	Nitrogen-free extracts: Carbohydrates
	Grams	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TURKEY RED WINTER WHEAT (PURE STRAIN NO. 42)							
Unselected	.0183	2.569	2.937	18.748	2.250	2.094	70.592
Large plump	.0284	2.246	2.617	16.710	2.152	2.908	73.367
Large shrivelled	.0181	2.651	3.228	20.605	2.253	2.817	68.446
Small plump	.0152	2.491	2.934	18.716	2.055	2.916	70.888
Small shrivelled	.0135	2.695	3.365	21.451	2.145	3.030	67.314
Dough stage	.0162	2.620	2.638	16.830	2.352	2.888	72.672
Average	.0182	2.545	2.953	18.843	2.201	2.910	70.546
TURKEY RED WINTER WHEAT (STANDARD VARIETY)							
Unselected	.0225	2.405	2.646	16.549	1.337	2.213	74.851
Large	.0298	2.101	2.255	14.093	1.100	2.486	77.965
Medium	.0262	2.161	2.256	14.108	.862	2.989	77.624
Small	.0199	2.213	2.269	13.924	1.442	2.795	77.357
Horny	.0204	2.336	2.770	17.313	1.615	2.770	73.196
Starchy	.0266	2.258	2.175	13.604	1.509	2.280	78.174
Average	.0242	2.245	2.395	14.931	1.310	2.588	76.527
BIG FRAME WINTER WHEAT							
Unselected	.0238	2.016	2.191	13.958	2.202	2.606	77.027
Large plump	.0271	2.180	2.213	14.123	1.986	2.257	77.241
Large shrivelled	.0225	2.031	2.367	15.097	2.175	2.375	75.955
Small plump	.0160	2.058	2.338	14.927	2.086	2.758	75.833
Small shrivelled	.0146	2.269	2.963	18.888	2.358	3.411	70.111
Dough stage	.0145	2.300	2.397	15.297	1.989	3.225	74.792
Horny	.0214	2.186	2.501	15.961	1.986	2.447	74.919
Starchy	.0243	2.149	1.990	12.705	2.165	2.509	78.482
Average	.0205	2.148	2.370	15.119	2.114	2.698	75.545
SCOTCH FIFE SPRING WHEAT							
Unselected	.0202	2.363	3.481	21.760	1.619	2.677	68.100
Large	.0249	2.284	3.211	20.063	1.570	2.867	70.005
Medium	.0203	2.105	3.456	21.604	1.938	2.692	68.205
Small	.0174	2.500	3.205	18.743	2.143	4.102	69.307
Milk stage	.00586	2.136	3.028	18.930	2.392	4.924	68.590
Average	.0177	2.277	3.076	20.220	1.932	3.452	68.841
MARQUIS SPRING WHEAT							
Large	.0250	2.522	3.299	21.053	2.439	2.273	68.414
Small	.0163	2.675	3.368	21.041	2.719	2.489	67.708
Average	.0206	2.598	3.333	21.047	2.579	2.386	68.061

[1]Sprout value data for this wheat are given in table 2. The composition is based upon moisture-free wheat.

[These analyses were made under the supervision of Dr. F. W. Upson, Station Chemist.]

Figures 1, 2, and 3 illustrate several grades of seed wheat studied for relative sprout value in 1913. The character of vegetative growth obtained in determining the sprout value of wheat grades is shown in figure 4. In this illustration, the wheat seedlings were in the proper stage for harvesting, all of the reserve food in the seed apparently having been utilized.

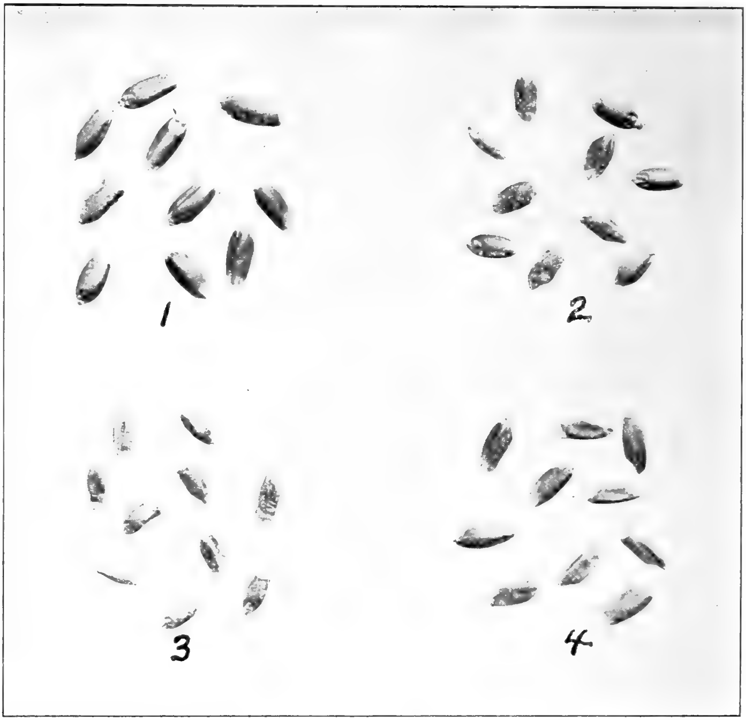


Fig. 1—Turkey Red grades tested for sprout value in 1913 (table 2). 1, large plump; 2, small plump; 3, small shrivelled; 4, dough stage. Relative weights of seed 100, 53, 48, 57. Relative sprout values of seed 100, 58, 40, 48. Slightly enlarged

Tables 2 and 3 contain a summary of the 1913 and 1914 sprout value determinations with various grades of winter and spring wheat.

In column 3 is recorded the moisture-free weight of 100 seeds for each grade. In columns 4, 6, and 8 are given the weight of

moisture-free substance contained in the stem growth and root growth and total vegetative growth from 100 seeds of each grade when tested for sprout value. In columns 5, 7, and 9 are indicated the ratios of the moisture-free sprout weights to the moisture-free weights of the seed tested. The percentage of

Fig. 2—Big Frame grades tested for sprout value in 1913 (table 2). 1, large plump; 2, small plump; 3, small shrivelled; 4, dough stage. Relative weights of seed 100, 59, 54, 53. Relative sprout values of seed 100, 68, 50, 58. Slightly enlarged

moisture in seed tested was determined from a parallel sample. In column 10 is given the weight of the inert seed residue remaining after the seedling extracted all available reserve food. In column 11 is given the actual weight of substance contained in the seed planted which was not recovered in either the vegetative growth or the inert seed remains. The ratio of this loss to the original weight of the seed is given in column 12. This loss in

TABLE 2—*Summary of sprout value determinations for different grades of wheat seeds (1913 crop)*

Kind of seed tested	No. of seeds tested	Weight of 100 seeds (moisture-free)	Sprout value of 100 seeds (moisture-free)						Weight of 100 seed remains (moisture-free)	Loss of seed substance for 100 seeds[1]	
			Stem growth		Root growth		Total vegetative growth				
			Weight	Ratio to seed	Weight	Ratio to seed	Weight	Ratio to seed		Weight	Ratio to seed
		Grams	*Grams*		*Grams*		*Grams*		*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
TURKEY RED WINTER WHEAT (PURE STRAIN No. 42)											
Unselected	1,070	1.83	.890	.48	.332	.18	1.222	.67	.181	.40	.22
Large plump	1,208	2.84	1.091	.38	.542	.19	1.633	.57	.255	.95	.33
Large shrivelled	1,142	1.81	.728	.40	.241	.13	.969	.53	.176	.66	.36
Small plump	1,000	1.52	.624	.41	.320	.21	.944	.62	.158	.41	.27
Small shrivelled	992	1.35	.441	.33	.217	.16	.658	.49	.163	.53	.39
Dough stage	1,500	1.62	.488	.30	.306	.19	.794	.49	.181	.65	.40
TURKEY RED WINTER WHEAT (STANDARD VARIETY)											
Unselected	1,062	2.25	.702	.31	.413	.18	1.115	.50	.212	.92	.41
Large	1,340	2.98	1.054	.35	.588	.20	1.642	.55	.236	1.10	.37
Medium size	1,502	2.62	.865	.33	.512	.19	1.377	.53	.197	1.05	.40
Small	1,433	1.99	.804	.40	.461	.23	1.265	.64	.253	.47	.24
Horny	1,420	2.04	.723	.35	.347	.17	1.070	.52	.186	.78	.38
Starchy	1,310	2.66	.868	.33	.496	.19	1.364	.51	.203	1.09	.41
BIG FRAME WINTER WHEAT											
Unselected	1,222	2.38	.736	.31	.401	.17	1.137	.48	.207	1.03	.43
Large plump	1,440	2.71	.842	.31	.560	.21	1.402	.52	.236	1.07	.39
Large shrivelled	1,531	2.25	.754	.33	.564	.25	1.318	.59	.154	.78	.35
Small plump	1,428	1.60	.566	.35	.396	.25	.962	.60	.152	.49	.31
Small shrivelled	1,407	1.46	.439	.30	.252	.17	.691	.47	.154	.61	.42
Dough stage	1,503	1.45	.486	.33	.331	.23	.817	.56	.123	.51	.35
Horny	1,241	2.14	.682	.32	.406	.19	1.088	.51	.181	.87	.41
Starchy	1,310	2.43	.709	.29	.497	.20	1.206	.50	.202	1.02	.42

TABLE 2 *Continued—Summary of sprout value determinations for different grades of wheat seeds (1913 crop)*

Kind of seed tested	No. of seeds tested	Weight of 100 seeds (moisture-free)	Sprout value of 100 seeds (moisture-free): Stem growth, Weight	Stem growth, Ratio to seed	Root growth, Weight	Root growth, Ratio to seed	Total vegetative growth, Weight	Total vegetative growth, Ratio to seed	Weight of 100 seed remains (moisture-free)	Loss of seed substance for 100 seeds[1]: Weight	Ratio to seed
		Grams	*Grams*		*Grams*		*Grams*		*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
SCOTCH FIFE SPRING WHEAT											
Unselected	1,200	2.02	.913	.45	.476	.24	1.389	.69	.207	.42	.21
Large	1,221	2.49	.994	.40	.426	.17	1.420	.57	.214	.86	.34
Small	1,211	1.74	.589	.34	.244	.14	.833	.48	.137	.77	.44
MARQUIS SPRING WHEAT											
Unselected	1,340	2.21	.950	.43	.202	.09	1.152	.52	.243	.81	.37
Large	1,480	2.50	1.130	.45	.364	.15	1.494	.60	.228	.77	.31
Small	1,412	1.63	.777	.48	.258	.16	1.035	.63	.180	.41	.25
Average, all wheat	1,305	2.10	.763	.36	.390	.19	1.154	.55	.193	.75	.36

[1]Results recorded in column (11) are the difference in moisture-free weight between the total vegetative growth plus the inert seed remains, and the original weight of the seed. This loss can be accounted for by respiratory activity and other complex metabolic changes. (See pages 20–23.)

Fig. 3—Spring wheat grades tested for sprout value in 1913 (table 2). 1 and 2, Scotch Fife large and small seeds; relative weights of seed 100, 76; relative sprout values of seed 100, 60. 3 and 4, Marquis large and small seeds; relative weights of seed 100, 65; relative sprout values of seed 100, 69. Slightly enlarged

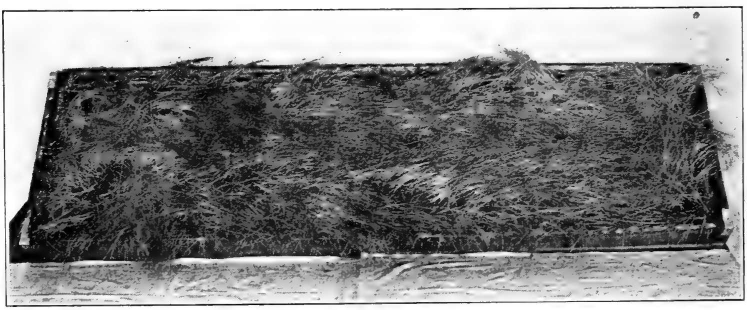


Fig. 4—Plant growth secured entirely from reserve food in wheat seeds. This wheat growth was secured in absolute darkness at 30° C. in a non-nutritive quartz medium watered with distilled water, for the purpose of determining its sprout value. The moisture-free weight of the stem and root growth obtained under these conditions has been termed "sprout value"

TABLE 3—*Summary of sprout value determinations for different grades of wheat seeds (1914 crop)*

Kind of seed tested	No. of seeds tested	Weight of 100 seeds (moisture-free)	Sprout value of 100 seeds (moisture-free): Stem growth		Root growth		Total vegetative growth		Weight of 100 seed remains (moisture-free)	Loss of seed substance for 100 seeds[1]	
			Weight	Ratio to seed	Weight	Ratio to seed	Weight	Ratio to seed		Weight	Ratio to seed
		Grams	*Grams*		*Grams*		*Grams*		*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
TURKEY RED WINTER WHEAT (PURE STRAIN NO. 42)											
Unselected........	981	1.83	.514	.28	.334	.18	.848	.46	.254	.73	.40
Large plump......	843	2.66	.694	.26	.466	.17	1.160	.44	.416	1.08	.41
Small plump......	900	1.94	.604	.31	.247	.13	.851	.44	.298	.79	.41
Small shrivelled....	1,050	1.13	.286	.25	.134	.12	.420	.37	.222	.48	.42
BIG FRAME WINTER WHEAT											
Unselected........	994	1.94	.516	.27	.194	.10	.710	.37	.317	.91	.47
Large plump......	860	2.52	.702	.28	.313	.12	1.015	.40	.316	1.18	.47
Small plump......	845	1.89	.604	.32	.256	.13	.860	.45	.231	.79	.42
Small shrivelled....	922	1.18	.325	.27	.075	.06	.400	.34	.176	.60	.51
SCOTCH FIFE SPRING WHEAT											
Unselected........	744	2.00	.901	.45	.345	.17	1.246	.62	.203	.55	.27
Large............	850	2.37	.674	.28	.486	.20	1.160	.49	.201	1.01	.43
Small............	700	1.70	.540	.32	.215	.13	.755	.44	.119	.82	.48
MARQUIS SPRING WHEAT											
Unselected........	750	2.11	.771	.36	.281	.13	1.052	.50	.230	.83	.39
Large............	844	2.41	.970	.40	.299	.12	1.269	.53	.231	.91	.38
Small............	693	1.47	.650	.44	.201	.14	.851	.58	.148	.47	.32
Average, all wheat	....	1.94	.625	.32	.274	.14	.899	.46	.240	.79	.41

[1]Results recorded in column (11) are the difference in moisture-free weight between the total vegetative growth plus the inert seed remains, and the original weight of the seed. This loss can be accounted for by respiratory activity and other complex metabolic changes.

TABLE 4—*Summary of sprout value determinations for different grades of wheat seeds. Data calculated on basis of the original unselected seed as 100 per cent (1913 crop)*[1]

Kind of seed	Relative weights of 100 seeds	Relative sprout values of 100 seeds (moisture-free)		
		Stem growth	Root growth	Total vegetative growth
	Per cent	*Per cent*	*Per cent*	*Per cent*
(1)	(2)	(3)	(4)	(5)
TURKEY RED WINTER WHEAT (PURE STRAIN NO. 42)				
Unselected	100	100	100	100
Large plump	155	123	163	134
Large shrivelled	99	82	73	79
Small plump	83	70	96	77
Small shrivelled	74	50	65	54
Dough stage	89	55	92	65
TURKEY RED WINTER WHEAT (STANDARD VARIETY)				
Unselected	100	100	100	100
Large	132	150	142	147
Medium	116	123	124	123
Small	88	115	112	113
Horny	91	103	84	96
Starchy	118	124	120	122
BIG FRAME WINTER WHEAT				
Unselected	100	100	100	100
Large plump	114	114	139	123
Large shrivelled	95	102	141	116
Small plump	67	77	99	85
Small shrivelled	61	60	63	61
Dough stage	61	66	83	72
Horny	90	93	101	96
Starchy	102	96	124	106
SCOTCH FIFE SPRING WHEAT				
Unselected	100	100	100	100
Large	123	108	89	102
Small	86	65	51	60
MARQUIS SPRING WHEAT				
Unselected	100	100	100	100
Large	113	119	180	130
Small	74	82	128	90

[1]These data are calculated from table 2.

substance is largely due to respiration and somewhat to other metabolic processes.

Altho there are some irregularities, due doubtless in part to experimental error, there is a marked general relationship between

the original weight of the seed and its sprout value, as may be seen upon a study of the tables.

As an average for all the grades of seed tested in 1913 and 1914, the total sprout value of the seed equaled 54.2 per cent and 46.3 per cent of the weight of seed planted in 1913 and 1914 respectively. The total loss of substance not recovered in either the sprout or the inert seed residues equaled 36.3 per cent and 40.7 per cent respectively in 1913 and 1914.

TABLE 5—*Summary of sprout value determinations for different grades of wheat seeds. Data calculated on basis of the original unselected seed as 100 per cent (1914 crop)*[1]

Kind of seed tested	Relative weights of 100 seeds	Relative sprout values of 100 seeds (moisture-free)		
		Stem growth	Root growth	Total vegetative growth
	Per cent	*Per cent*	*Per cent*	*Per cent*
TURKEY RED WINTER WHEAT (PURE STRAIN NO. 42)				
Unselected	100	100	100	100
Large plump	145	135	140	137
Small plump	106	117	74	100
Small shrivelled	62	56	40	50
BIG FRAME WINTER WHEAT				
Unselected	100	100	100	100
Large plump	130	136	161	143
Small plump	97	117	132	121
Small shrivelled	61	63	39	56
SCOTCH FIFE SPRING WHEAT				
Unselected	100	100	100	100
Large	118	75	141	93
Small	85	60	62	61
MARQUIS SPRING WHEAT				
Unselected	100	100	100	100
Large	114	126	106	121
Small	70	84	72	81

[1]These data are calculated from table 3.

Tables 4 and 5 contain a brief summary of the sprout value determinations and show the ratios of the various grades of seed (for each variety) to the original unselected seed.

The principle is clearly brought out in table 6, which is a grand summary table compiled from tables 2 and 3. The grades for all varieties tested during the 2 years are here grouped into

the three grades—(1) original, (2) large, and (3) small. The ratios for the moisture-free weight of the unselected seed to the large and small seed were respectively 100:127 and 100:85, while the ratios for the total sprout value were 100:123 and 100:88 respectively. This would indicate a rather close relationship between the size of the seed and its sprout value.

TABLE 6—*Summary of the sprout value determinations for three distinct grades of all wheat varieties tested in 1913 and 1914*[1]

Kind of seed tested	Relative weights of 100 seeds	Relative sprout values of 100 seeds (moisture-free)		
		Stem growth	Root growth	Total vegetative growth
	Per cent	*Per cent*	*Per cent*	*Per cent*
1913 CROP				
Unselected	100	100	100	100
Large[2]	126	122	136	126
Small[3]	80	82	97	85
1914 CROP				
Unselected	100	100	100	100
Large[2]	127	118	137	123
Small[3]	89	94	85	91
AVERAGE 1913 AND 1914				
Unselected	100	100	100	100
Large[2]	127	120	137	125
Small[3]	85	88	91	88

[1]These data are calculated from tables 2 and 3.

[2]Seed classes indicated in tables 2 and 3 as "large" and "large plump" seed are here averaged in one group designated as "large" seed.

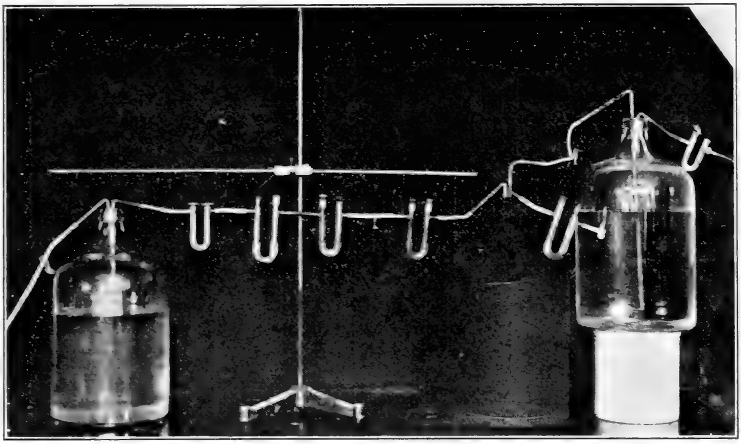
[3]Seed classes indicated in tables 2 and 3 as "small" and "small plump" seed are here averaged in one group designated as "small" seed.

LOSS OF SEED SUBSTANCE THRU RESPIRATION

The sprout value determinations given in tables 2 and 3 indicate that an actual loss of seed substances occurred which was not recovered in either the vegetative growth or the inert seed residue. A respiration test was made in triplicate which partially accounts for this loss.

Apparatus was set up as shown in figure 5. Two hundred small plump Turkey Red wheat seeds were planted in the 20-liter, light-proof bottle No. 1, containing a small quantity of nonnutritive quartz medium. The seed was watered with distilled water from bottle No. 2 and the air was syphoned off thru bottle No. 3. U-tubes Nos. A_1, A_2, and A_3 contained KOH which extracted all CO_2 from the air passing thru them. U-tubes

B_1, B_2, and B_3 contained H_2SO_4, which extracted all moisture from the air. The U-tubes A_1 and A_2 prevent external atmospheric CO_2 from entering the wheat bottle No. 1. U-tube B_1 prevents any moisture reaching U-tube No. A_3 which extracts and retains the CO_2 liberated from the sprouting wheat in bottle No. 1. Some water is formed by chemical action when the CO_2 combines with the KOH in U-tube No. A_3. This moisture is taken up by the H_2SO_4 in U-tube No. B_2. Thus the difference



3 B_3 B_2 A_3 B_1 1 A_2 2 A_1

Fig. 5—(1) Light proof bottle in which seedlings were grown in a nonnutritive quartz medium. (2) Bottle of distilled water for watering seedlings. (3) Bottle of water for syphoning off air. (A_1, A_2, A_3) U-tubes containing K O H for extracting CO_2 from air. (B_1, B_2, B_3) U-tubes containing H_2 SO_4 for extracting moisture from the air

between initial and final weights of U-tubes A_3 plus B_2 indicates the amount of CO_2 given off by the wheat seedlings as the result of respiration during germination and growth to the stage where all reserve food stored in the seeds has been translocated. The U-tube B_3 removes all moisture from any possible back-flow of air from bottle No. 3.

The seedlings were grown in bottle No. 1 entirely from the reserve food within the seed until the supply was exhausted and further growth terminated. Under the temperature conditions of this test a period of 14 days was required to exhaust this reserve food supply within the seed. The seedlings were then carefully washed from the sand, and the dry matter in the root

TABLE 7—*Loss of seed substance as carbon dioxide (CO_2) by respiration of germinating Turkey Red winter wheat seed. Growth dependent entirely upon reserve food of seed*

Test No.	Average seed weight (moisture-free)	Days' growth	Plants grown	Gain in weight of tube	Carbon dioxide loss per seed		Sprout value per seed (moisture-free)				Seed residue	Plant returned[1]	Unaccounted gain over original seed weight[2]
					Weight	Ratio to seed	Stem growth	Root growth	Total vegetative growth: Weight	Total vegetative growth: Ratio to seed			
	Grams			*Grams*	*Grams*		*Grams*	*Grams*	*Grams*		*Grams*	*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1.........	.01711	14	138	.9318	.00675	.3945	.00663	.00138	.00801	.4681	.00260	.01061	.00025
2.........	.01711	14	183	1.2524	.00666	.3893	.00681	.00136	.00817	.4775	.00287	.01104	.00059
3.........	.01711	14	163	1.0921	.00672	.3927	.00672	.00137	.00809	.4728	.00273	.01082	.00043
Average..	.01711	14	161	1.0921	.00671	.3922	.00672	.00137	.00809	.4728	.00273	.01082	.00042

[1]This item consists of the total vegetative growth plus the inert seed residue as given in columns (10) and (12).
[2]This item consists of the difference between the original seed weight and the sum of the CO_2 loss (column 6), the total vegetative growth (column 10), and the inert seed residue (column 12).

and stem growth and inert seed remains determined. The results of the three separate tests are given in table 7 together with the average for all three tests. The average dry matter in the total vegetative growth (stem and root growth) equaled 47.28 per cent of the original dry matter in the seed. The average carbon dioxide liberated equaled 39.22 per cent of the original moisture-free seed. The combined weights of the root growth, stem growth, CO_2, and inert seed residue exceeded the moisture-free weight of the seed 2.4 per cent. This slight discrepancy may result in part from the manner of determining the moisture-free weight of the seed planted. The sample to be germinated could not be dried at 110° C. without destroying its viability. Consequently, the moisture-free weight of a parallel sample from the same composite lot of seed was used. The samples may not have been exact duplicates.

RELATION OF SIZE AND SPROUT VALUE OF SEED TO YIELD AT DIFFERENT DEPTHS OF PLANTING

For the purpose of supplementing the sprout value determinations (pp. 10-20) with wheat seeds of various grades, several distinct grades of fall and spring wheat were grown during 1914 and 1915 at different depths of planting in the wheat nursery. The object of the tests was to determine the relation of size and sprout value of wheat seed to its relative ability to germinate, grow, and yield as the depth of planting is increased. (The customary depth in farm practice is about 2 inches.)

All plantings were made by hand at the ordinary field rate, in duplicate nursery blocks containing 5 rows, 7½ feet long and 8 inches apart. The two outside rows of each block were discarded at time of harvest to eliminate the effect of competition between plats.

The results for 3 grades of Turkey Red winter wheat planted 1, 3, and 5 inches deep are recorded in table 8, while table 9 summarizes the results for two grades each of Scotch Fife and Marquis spring wheat.

In case of the winter wheat, as shown in table 8, small plump winter wheat seed appeared to be at no disadvantage when planted up to a depth of 5 inches, as compared with large plump seed, even tho the sprout value was only 64.3 per cent as large. However, the small shrivelled seed, having only 38.6 per cent as much sprout value as the large plump seed, was at a marked disadvantage when planted either 3 or 5 inches deep.

As an average for the two varieties of spring wheat, small seed (having a relatively lower sprout value of 29.7 per cent than the large seed) was at a relatively greater disadvantage than the

TABLE 8—*Summary of Turkey Red winter wheat grades compared at three depths of planting (two-year average, 1914 and 1915)*

Kind of seed planted	Seed planted						Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Depth planted	Germination		No. of culms per row	Yield per row			
					Field	Laboratory		Grain	Straw	Total	Ratio grain to straw[1]
(1)	*Grams* (2)	*Grams* (3)	(4)	*Inches* (5)	*Per cent* (6)	*Per cent* (7)	(8)	*Grams* (9)	*Grams* (10)	*Grams* (11)	(12)
ONE INCH DEEP											
Large plump	2.75	1.396	180	1	79.1	87.5	354.8	130.6	385.3	515.9	.33
Small plump	1.73	.897	180	1	79.2	84.5	338.0	138.0	370.4	508.4	.36
Small shrivelled	1.24	.539	180	1	70.4	80.7	306.5	121.8	335.2	457.0	.36
THREE INCHES DEEP											
Large plump	2.75	1.396	180	3	74.2	87.5	337.8	157.8	400.3	558.1	.39
Small plump	1.73	.897	180	3	68.4	84.5	301.3	146.0	354.1	500.1	.46
Small shrivelled	1.24	.539	180	3	66.1	80.7	250.6	119.1	285.8	404.9	.41
FIVE INCHES DEEP											
Large plump	2.75	1.396	180	5	33.2	87.5	196.8	100.8	255.7	356.5	.37
Small plump	1.73	.897	180	5	36.3	84.5	208.3	107.3	282.7	390.0	.37
Small shrivelled	1.24	.539	180	5	18.7	80.7	94.0	58.0	144.6	202.6	.24
RELATIVE RESULTS BASED ON LARGE SEED											
	Per cent	*Per cent*	*Per cent*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
ONE INCH DEEP											
Large plump	100.0	100.0	100.0	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small plump	62.9	64.3	100.0	1	100.1	96.6	95.3	105.7	96.1	98.5	110.0
Small shrivelled	45.1	38.6	100.0	1	89.0	92.2	86.4	93.3	87.0	88.6	110.0
THREE INCHES DEEP											
Large plump	100.0	100.0	100.0	3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small plump	62.9	64.3	100.0	3	92.2	96.6	89.2	92.5	88.5	89.6	118.0
Small shrivelled	45.1	38.6	100.0	3	89.1	92.2	74.2	75.5	71.4	72.5	105.1
FIVE INCHES DEEP											
Large plump	100.0	100.0	100.0	5	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small plump	62.9	64.3	100.0	5	109.3	96.6	105.8	106.5	110.5	109.4	100.0
Small shrivelled	45.1	38.6	100.0	5	56.3	92.2	47.8	57.5	56.5	56.8	64.9

[1]Average of ratios for 2 years.

TABLE 9—*Summary of spring wheat grades compared at four depths of planting (two-year average 1914 and 1915)*

Grade of seed planted	Seed planted						Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Depth planted	Germination: Field	Germination: Laboratory	No. of culms per row	Yield per row: Grain	Yield per row: Straw	Yield per row: Total	Ratio wt. grain to wt. straw[1]
	Grams	*Grams*		*Inches*	*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Large	2.44	1.336	180	1	70.0	84.6	200.6	35.3	224.1	259.4	.17
Small	1.64	.868	180	1	65.7	84.2	186.4	29.8	226.1	255.9	.13
Large	2.44	1.336	180	3	69.4	84.6	223.0	46.0	275.7	321.7	.18
Small	1.64	.868	180	3	65.0	84.2	182.8	27.2	229.0	256.2	.13
Large	2.44	1.336	180	4	55.9	84.6	175.5	31.8	218.1	249.9	.15
Small	1.64	.868	180	4	48.7	84.2	117.6	20.1	156.6	176.7	.14
Large	2.44	1.336	180	6	27.7	84.6	39.2	14.8	62.2	77.0	.24
Small	1.64	.868	180	6	25.5	84.2	16.9	9.3	44.3	53.6	.21
RELATIVE RESULTS BASED ON LARGE SEED											
	Per cent	*Per cent*	*Per cent*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Large	100.0	100.0	100.0	1	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small	67.2	64.9	100.0	1	93.9	99.5	92.9	84.4	100.9	98.6	76.5
Large	100.0	100.0	100.0	3	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small	67.2	64.9	100.0	3	93.7	99.5	82.0	59.1	88.1	79.6	72.2
Large	100.0	100.0	100.0	4	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small	67.2	64.9	100.0	4	87.1	99.5	67.0	63.2	71.8	70.7	93.3
Large	100.0	100.0	100.0	6	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Small	67.2	64.9	100.0	6	92.1	99.5	43.1	62.8	71.2	69.6	87.5

[1]Average of ratios for 2 years.

large seed when planted 3 or more inches deep. The disadvantage of the small seed increased somewhat irregularly as the depth of planting increased.

Where the stand and yield of wheat were reduced by too deep planting, it is apparent that the reduction was not consistently proportional to the reserve food content of different grades.

COMPETITION BETWEEN PLANTS OF CEREAL CROPS

Most seed of the cereal crops as prepared for planting by the farmer is a composite of large, small, and intermediate sizes. It is of interest to know the effect of competition upon the relative behavior of plants grown from the large and small seed when planted thus in close proximity.

It is also of interest to know the extent to which the principle of competition may act as a factor in maintaining or improving the yield of cereal crops. Montgomery (1912), in an earlier bulletin from this Station on "Competition in Cereals," has suggested "it is possible that the custom of placing in the soil seeds for two or three times as many plants as are really necessary to occupy the land has resulted in a continuous natural selection of the strongest and most productive." Within a variety, there would seem to be a continual natural elimination of the least adapted types or strains as the result of competition.

In the investigations which follow, the conclusions are based upon the yields of grain and straw, and the number of culms.

TABLE 10—*Error in separation of mature wheat crop into individual plants*

Kind of crop	Year	Total number of plants examined	Number of incorrect separations	Error in separation
				Per cent
Winter wheat...........	1915	8,640	553	6.4
Spring wheat...........	1916	3,540	312	8.8

The number of plants surviving at harvest time was not determined because tests indicated that reliable separations of the crop into individual plants could not be made where plants of only one variety were grown. In two experiments where alternating plants of bearded and beardless varieties of wheat were grown 0.5 inch apart in the row, a separation of plants based upon the appearance of the roots was made. Following this separation, an examination of the heads within a supposedly

single plant indicated in many cases a mixture of varieties. The degree of such error in the separation of plants averaged 7.6 per cent as shown in table 10.

EFFECT OF COMPETITION BETWEEN PLANTS GROWN FROM SEEDS DIFFERING MARKEDLY IN SIZE AND SPROUT VALUE

The plan of this experiment was to alternate in the row, at the ordinary field rate of planting, both large and small wheat seeds, and to determine at harvest the relative productiveness of the two grades as compared with the relative yields when planted alone. The investigation was made with both winter and spring wheat. In order to enable a separation of mature plants, grown in competition, it seemed necessary to use two varieties of wheat with some definite distinguishing feature. Consequently, a bearded and a beardless variety were chosen for both the winter and the spring wheat. These were respectively Turkey Red and Big Frame for the winter wheat, and Scotch Fife and Marquis for the spring wheat. Reciprocal tests were made in which, for example, large seed of Turkey Red was alternated with small seed of Big Frame in the one case and small seed of the Turkey Red and large seed of the Big Frame in the other. By this arrangement, the effects of variety competition were largely counterbalanced.

The plats used were 7½ feet long and contained 5 rows spaced 8 inches apart. No additional space was left between plats, but the two outside rows were discarded in all cases to prevent the effect of plat competition as a source of error. The seeds were spaced one-half inch apart in the row which corresponds to the normal rate used in farm practice.

The initial number of plants was counted for each plat and the per cent stand or field germination calculated. One hundred and eighty seeds were planted per row. In these rows where alternating seeds of the two varieties were planted in competition, only 90 seeds of each variety were used per row. The yields, however, have been calculated on the basis of 180 seeds planted in all cases in order that the data be comparable.

The number of culms and the yield of grain and straw per 180 seeds planted were determined for all tests.

The results are contained in tables 11 to 14 and are summarized in table 15. In these tables, the ratio of results from small seed to the results from large seed has been calculated. At the bottom of each table is given the average of ratios between grades for reciprocal varieties. Thus, the effect of variety differences and variety competition has been eliminated in the summary data, because both the small and the large seed are represented by both varieties.

TABLE 11—*Yields from large and small wheat seed when planted alone and in competition (1915)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per 180 seeds	Yield per 180 seeds planted			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw
(1)	*Grams* (2)	*Grams* (3)	(4)	*Per cent* (5)	*Per cent* (6)	(7)	*Grams* (8)	*Grams* (9)	*Grams* (10)	(11)
LARGE BIG FRAME AND SMALL TURKEY RED										
Grades alone										
Large Big Frame	2.52	1.015	180	83.8	86	368	142	496	638	.29
Small Turkey Red	1.94	.851	180	71.4	80	373	169	461	630	.37
Ratio, small T. R. to large B. F	.77	.84	1.00	.85	.93	1.01	1.19	.93	.99	1.28
Grades competing										
Large Big Frame	2.52	1.015	90	78	86	440	184	542	726	.34
Small Turkey Red	1.94	.851	90		80	316	128	340	468	.38
Ratio, small T. R. to large B. F	.77	.84	1.00	....	.93	.72	.70	.63	.64	1.12
LARGE TURKEY RED AND SMALL BIG FRAME										
Grades alone										
Large Turkey Red	2.66	1.160	180	77.2	80.5	389	161	453	614	.35
Small Big Frame	1.89	.860	180	81.1	85.0	347	128	465	593	.27
Ratio, small B. F. to large T. R	.71	.74	1.00	1.05	1.06	.89	.80	1.03	.97	.77
Grades competing										
Large Turkey Red	2.66	1.160	90	80	80.5	368	150	402	552	.37
Small Big Frame	1.89	.860	90		85.0	360	146	376	522	.39
Ratio, small B. F. to large T. R	.71	.74	1.00	....	1.06	.98	.97	.93	.95	1.05
AVERAGE OF RATIOS BETWEEN GRADES FOR RECIPROCAL VARIETIES										
Grades alone										
Ratio, small to large	.74	.79	1.00	....	.99	.95	.99	.98	.98	1.02
Grades competing										
Ratio, small to large	.74	.79	1.00	....	.99	.85	.83	.78	.79	1.08

TABLE 12—*Yields from large and small wheat seed when planted alone and in competition (1914)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination: Field	Germination: Laboratory	No. of culms per 180 seeds	Yield per 180 seeds planted: Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE BIG FRAME AND SMALL TURKEY RED										
Grades alone										
Large Big Frame	2.71	1.402	180	80	89	308.9	100.6	362.4	463.0	.28
Small Turkey Red	1.52	.944	180	82	90	374.1	99.9	384.4	484.3	.26
Ratio, small T. R. to large B. F	.56	.67	1.00	1.02	1.01	1.21	.99	1.06	1.05	.93
Grades competing										
Large Big Frame	2.71	1.402	90	80.2	89	305.8	93.2	372.0	165.2	.25
Small Turkey Red	1.52	.944	90		90	326.4	81.6	354.4	436.0	.23
Ratio, small T. R. to large B. F	.56	.67	1.00	....	1.01	1.07	.88	.95	.94	.92
LARGE TURKEY RED AND SMALL BIG FRAME										
Grades alone										
Large Turkey Red	2.84	1.633	180	83	89	357.9	111.2	375.9	487.1	.29
Small Big Frame	1.60	.962	180	79	92	279.6	91.3	311.5	402.8	.29
Ratio, small B. F. to large T. R	.56	.59	1.00	.95	1.03	.78	.82	.83	.83	1.00
Grades competing										
Large Turkey Red	2.84	1.633	90	81	89	480.0	132.2	565.4	697.6	.23
Small Big Frame	1.60	.962	90		92	213.8	46.8	276.6	323.4	.17
Ratio, small B. F. to large T. R	.56	.59	....	....	1.03	.44	.35	.49	.49	.74
AVERAGE OF RATIOS BETWEEN GRADES FOR RECIPROCAL VARIETIES										
Grades alone										
Ratio, small to large	.56	.63	1.00	....	1.02	.99	.90	.94	.94	.96
Grades competing										
Ratio, small to large	.56	.63	1.00	....	1.02	.75	.61	.72	.71	.83

TABLE 13—*Yields from large and small wheat seed when planted alone and in competition (1914)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination: Field	Germination: Laboratory	No. of culms per 180 seeds	Yield per 180 seeds planted: Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE SCOTCH FIFE AND SMALL MARQUIS										
Grades alone										
Large Scotch Fife	2.49	1.420	180	77	89	328.4	38	314.0	352.0	.12
Small Marquis	1.63	1.035	180	68	87	300.4	43	314.0	357.0	.14
Ratio, small M. to large S. F	.65	.73	1.00	....	.98	.92	1.13	1.00	1.01	1.17
Grades competing										
Large Scotch Fife	2.49	1.420	90	73	89	322.2	35	293.6	328.6	.12
Small Marquis	1.63	1.035	90		87	368.2	36.2	271.8	308.0	.13
Ratio, small M. to large S. F	.65	.73	1.00	....	.98	1.14	1.03	.93	.94	1.08
LARGE MARQUIS AND SMALL SCOTCH FIFE										
Grades alone										
Large Marquis	2.50	1.494	180	64	88	328.0	49.7	336.3	386.0	.15
Small Scotch Fife	1.74	.833	180	74	87	317.8	32.0	291.0	323.0	.11
Ratio, small S. F. to large M	.70	.56	1.00	....	.99	.97	.64	.87	.84	.73
Grades competing										
Large Marquis	2.50	1.494	90	73	88	341.2	54.8	354.4	409.2	.15
Small Scotch Fife	1.74	.833	90		87	240.0	28.8	223.2	252.0	.13
Ratio, small S. F. to large M	.70	.56	1.00	....	.99	.70	.53	.63	.62	.87
AVERAGE OF RATIOS BETWEEN GRADES FOR RECIPROCAL VARIETIES										
Grades alone										
Ratio, small to large	.67	.64	1.00	....	.98	.94	.88	.93	.92	.95
Grades competing										
Ratio, small to large	.67	.64	1.00	....	.98	.92	.78	.78	.78	.97

TABLE 14—*Yields from large and small wheat seed when planted alone and in competition (1915)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per 180 seeds	Yield per 180 seeds planted			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE SCOTCH FIFE AND SMALL MARQUIS										
Grades alone										
Large Scotch Fife	2.37	1.160	180	61.1	79.0	132	63	223	286	.28
Small Marquis	1.47	.851	180	61.1	81.8	107	53	181	234	.29
Ratio, small M. to large S. F.	.62	.73	....	....	1.04	.81	.84	.81	.82	1.04
Grades competing										
Large Scotch Fife	2.37	1.160	90	64	79.0	144	48	206	254	.23
Small Marquis	1.47	.851	90		81.8	102	46	126	172	.36
Ratio, small M. to large S. F.	.62	.73	....	....	1.04	.71	.96	.61	.68	1.56
LARGE MARQUIS AND SMALL SCOTCH FIFE										
Grades alone										
Large Marquis	2.41	1.269	180	60.5	82.4	116	65	194	259	.33
Small Scotch Fife	1.70	.755	180	66.1	81.2	111	50	205	255	.24
Ratio, small S. F. to large M.	.71	.60	....	....	.99	.96	.77	1.06	.98	.73
Grades competing										
Large Marquis	2.41	1.269	90	67	82.4	126	54	176	230	.31
Small Scotch Fife	1.70	.755	90		81.2	108	36	152	188	.24
Ratio, small S. F. to large M.	.71	.60	....	....	.99	.86	.68	.86	.82	.77
AVERAGE OF RATIOS BETWEEN GRADES FOR RECIPROCAL VARIETIES										
Grades alone										
Ratio, small to large	.66	.66	1.00	....	1.01	.88	.80	.93	.90	.88
Grades competing										
Ratio, small to large	.66	.66	1.00	....	1.01	.78	.82	.73	.75	1.16

TABLE 15—*Summary showing relative yields of small and large wheat seed when planted alone and in competition (two-year average, 1914 and 1915)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per 180 seeds	Yield per 180 seeds planted			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw[1]
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
TWO-YEAR AVERAGE FOR TWO VARIETIES OF WINTER WHEAT										
Grades alone										
Ratio, small to large	.65	.71	1.00	....	1.00	.97	.94	.96	.96	.99
Grades competing										
Ratio, small to large	.65	.71	1.00	....	1.00	.80	.72	.75	.75	.95
TWO-YEAR AVERAGE FOR TWO VARIETIES OF SPRING WHEAT										
Grades alone										
Ratio, small to large	.67	.65	1.00	....	.99	.91	.84	.93	.91	.91
Grades competing										
Ratio, small to large	.67	.65	1.00	....	.99	.85	.80	.75	.76	1.06
TWO-YEAR AVERAGE FOR WINTER AND SPRING WHEAT										
Grades alone										
Ratio, small to large	.66	.68	1.00	....	.99	.94	.89	.94	.93	.95
Grades competing										
Ratio, small to large	.66	.68	1.00	....	.99	.82	.76	.75	.75	1.00

[1]Average of ratios for two years.

The yields of wheat during the 2 years of these tests were quite normal. The averages of all the winter wheat yields were at the rates of 31 and 48 bushels per acre during 1914 and 1915 respectively. The corresponding spring wheat yields were at the rates of 13 and 17 bushels per acre. This was a normal difference in yield for winter and spring wheats—the former representing a well adapted, and the latter a poorly adapted crop.

It is seen from the summary data in table 15 that, as an average for both winter and spring wheat during the 2 years, the small seed weighed 66 per cent as much as the large seed and had a sprout value 68 per cent as great. The laboratory germination of the two grades was practically equal—the small seed germinating one per cent less as an average.

When planted alone, the small seed produced 6 per cent fewer culms, and in competition 18 per cent fewer culms than the large seed. The yield of grain was 11 per cent smaller for the small seed planted alone and 24 per cent smaller in competition than for the large seed. The straw yield was 6 per cent smaller for the small seed alone and 25 per cent smaller in competition than for the large seed. The total plant yield was 7 per cent smaller for the small seed planted alone and 25 per cent smaller in competition than for the large seed.

It is evident that, when planted alone in equal numbers, small seed was (on an average) 11 per cent and 7 per cent inferior to large seed in grain and total production, respectively. Competition reduced the relative yield of small seed in grain and total production 15 and 20 per cent respectively.

EFFECT UPON TOTAL YIELD OF COMPETITION BETWEEN LARGE AND SMALL SEEDS

The investigation reported in tables 16, 17, 18, and 19 indicates the effect upon total yield of wheat from planting large and small seeds of the same variety in competition. Large and small seeds of a given wheat variety were alternated in 5-row plats 7½ feet long. The seeds were spaced one-half inch apart by hand. The two grades were also planted alone to secure the comparative yields free from grade competition. A difference between the yield of the two grades mixed and the average yield of the two grades planted alone indicates the effect of competition upon total yield. This test was made with two varieties each of winter and spring wheat during 1914 and 1915. The plats were systematically distributed and were replicated 5 and 9 times for the winter and spring wheat respectively. Being of the same variety, it was not possible to distinguish and separate the

TABLE 16—*Results from winter wheat grades grown to determine the extent of competition between grades of the same variety (1914 and 1915)*[1]

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per row	Yield per row			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw[2]
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
AVERAGE FOR 1914 AND 1915										
Turkey Red winter wheat										
Grades alone										
Large plump	2.75	1.396	180	79.1	87.5	373.4	136.1	414.6	550.7	.325
Small plump	1.73	.897	180	77.2	84.5	373.5	134.9	422.8	557.7	.311
Average, large and small plump	2.24	1.146	180	78.1	86.0	373.4	135.5	418.7	554.2	.318
Grades competing										
Large and small plump	2.24	1.146	180	78.7	86.0	370.4	132.7	423.1	555.8	.312
Grades alone										
Large plump	2.75	1.396	180	79.1	87.5	373.4	136.1	414.6	550.7	.325
Small shrivelled	1.24	.539	180	71.3	80.7	337.6	131.8	399.9	531.7	.327
Average, large plump and small shrivelled	1.99	.967	180	75.2	84.1	355.5	133.9	407.2	541.2	.326
Grades competing										
Large plump and small shrivelled	1.99	.967	180	76.3	84.1	378.6	129.5	431.6	561.1	.298
YEAR 1915										
Turkey Red winter wheat										
Grades alone										
Small plump	1.94	.851	180	71.4	80.0	373.0	169.0	461.2	630.2	.366
Small shrivelled	1.13	.420	180	66.6	78.0	330.0	157.4	419.3	576.7	.375
Average, small plump and small shrivelled	1.54	.636	180	69.0	79.0	351.5	163.2	440.2	603.4	.370
Grades competing										
Small plump and small shrivelled	1.54	.636	180	68.5	79.0	381.0	162.0	463.7	625.7	.349

[1]The crop was grown at the ordinary field rate in 5-row nursery plats, replicated five times. Yields based on 3 center rows.
[2]Average of ratios for two years in those tests which were made two years.

TABLE 17—*Results from winter wheat grades grown to determine the extent of competition between grades of the same variety (1915)*[1]

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per row	Yield per row			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw[2]
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
BIG FRAME WINTER WHEAT										
Grades alone										
Large plump	2.52	1.015	180	83.8	86.0	368.0	142.0	496.0	638.0	.286
Small plump	1.89	.860	180	81.1	80.5	347.0	128.0	465.0	593.0	.275
Average, large and small plump	2.20	.937	180	82.4	83.2	357.5	135.0	480.5	615.5	.280
Grades competing										
Large and small plump	2.20	.937	180	81.6	83.2	358.0	146.0	460.0	606.0	.317
Grades alone										
Large plump	2.52	1.015	180	83.8	86.0	368.0	142.0	496.0	638.0	.286
Small shrivelled	1.18	.400	180	76.9	80.0	346.0	154.0	448.0	602.0	.344
Average, large plump and small shrivelled	1.85	.707	180	80.3	83.0	357.0	148.0	472.0	620.0	.315
Grades competing										
Large plump and small shrivelled	1.85	.707	180	78.8	83.0	369.0	135.0	482.0	617.0	.280
Grades alone										
Small plump	1.89	.860	180	81.1	80.5	347.0	128.0	465.0	593.0	.275
Small shrivelled	1.18	.400	180	76.9	80.0	346.0	154.0	448.0	602.0	.344
Average, small plump and small shrivelled	1.53	.630	180	79.0	80.2	346.5	141.0	456.5	597.5	.309
Grades competing										
Small plump and small shrivelled	1.53	.630	180	80.0	80.2	360.0	141.0	497.0	638.0	.284

[1]The crop was grown at the ordinary field rate in 5-row nursery plats, replicated five times. Yields based on 3 center rows.
[2]Average of ratios for two years in those tests which were made two years.

TABLE 18—*Results from spring wheat grades grown to determine the extent of competition between grades of the same variety (two-year average, 1914 and 1915)*[1]

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per row	Yield per row			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw[2]
(1)	*Grams* (2)	*Grams* (3)	(4)	*Per cent* (5)	*Per cent* (6)	(7)	*Grams* (8)	*Grams* (9)	*Grams* (10)	(11)
SCOTCH FIFE SPRING WHEAT										
Grades alone										
Large	2.43	1.290	180	69.0	84.0	230.2	50.5	268.5	319.0	.20
Small	1.72	.794	180	70.0	84.1	214.4	39.9	237.7	277.6	.18
Average, large and small	2.07	1.042	180	69.5	84.0	222.3	45.2	253.1	298.3	.19
Grades competing										
Large and small	2.07	1.042	180	69.5	84.0	225.6	48.0	263.5	311.5	.19
MARQUIS SPRING WHEAT										
Grades alone										
Large	2.45	1.381	180	62.2	85.2	222.0	57.3	265.1	322.4	.21
Small	1.55	.943	180	64.5	84.4	203.7	50.9	241.5	292.4	.21
Average, large and small	2.00	1.162	180	63.3	84.8	212.8	54.1	253.3	307.4	.21
Grades competing										
Large and small	2.00	1.162	180	64.3	84.8	208.7	50.3	234.6	285.9	.23

[1]The crop was grown at the ordinary field rate in 5-row nursery plats, replicated nine times. Results based on 3 center rows.
[2]Average of ratios for two years.

TABLE 19—*Summary showing the effect upon the crop of planting large and small seed of the same wheat variety in competition. (Two-year average of 4 varieties, 1914 and 1915)*[1]

	Large seed alone	Small seed alone	Average large and small seed	Large and small seed competing
(1)	(2)	(3)	(4)	(5)
ACTUAL RESULTS				
Weight of 100 seeds planted (grams)	2.57	1.55	2.06	2.06
Sprout value of 100 seeds (grams)	1.249	.739	.993	.993
Number seeds planted per row	180	180	180	180
Germination in field (per cent)	76.2	73.5	74.8	74.9
Germination in laboratory (per cent)	86.0	82.4	84.2	84.2
Number of culms per row	322.5	303.7	311.4	318.7
Yield of grain per row (grams)	110.7	106.6	108.6	107.0
Yield of straw per row (grams)	392.5	369.2	380.8	382.5
Total yield per row (grams)	503.2	475.8	489.4	489.5
Ratio of grain to straw	.27	.27	.27	.27
RELATIVE RESULTS BASED ON LARGE SEED				
Weight of 100 seeds planted (per cent)	100	60.3	80.2	80.2
Sprout value of 100 seeds (per cent)	100	59.2	79.5	79.5
Number seeds planted (per cent)	100	100.0	100.0	100.0
Germination in field (per cent)	100	96.5	98.2	98.3
Germination in laboratory (per cent)	100	95.8	97.9	97.9
Number of culms per row (per cent)	100	94.2	96.6	98.8
Yield of grain per row (per cent)	100	96.3	98.1	96.6
Yield of straw per row (per cent)	100	94.1	97.0	97.4
Total yield per row (per cent)	100	94.5	97.3	97.3
Ratio grain to straw (per cent)	100	100	100	100

[1]Data compiled from tables 10 and 11, using all tests in which large and small plump or large and small shrivelled seeds were compared.

crop from each of the two distinct grades at harvest, and it was only possible to determine the combined yield when grown in competition in the same row.

Table 19 summarizes the results for all varieties during both years. The small seeds weighed 60.3 per cent as much and their sprout value was 59.2 per cent as great as for the large seed. Practically the same results were obtained from the two grades planted in competition as the average results for the two grades planted alone. It would appear that if the plants from the small seeds were at a disadvantage when grown in competition, those from the large seeds must have had an advantage of approximately the same magnitude.

EFFECT OF COMPETITION BETWEEN VARIETIES

Further information regarding the principle of competition between plants was obtained by growing alternate plants of two varieties of wheat and comparing the relative results with those obtained when the varieties were grown alone. Seed of approximately the same size were selected for each variety in order to eliminate the size of seed as a factor in the competition. Five-row nursery plats $7\frac{1}{2}$ feet long were used. The plats within a test were systematically distributed and replicated 5 times each year for winter wheat and 9 times for spring wheat. The tests were duplicated with both large and small seeds. The results are given in tables 20 to 23. Because of a seasonal difference in the relative behavior of two varieties, the results for each year should be considered individually. The behavior of the varieties in plats where the seed of each was planted alone shows conclusively that the season had different effects on the varieties in different years.

Results for 1914—As an average for both the large and small seed tests with winter wheat in 1914 (table 20), in which there was practically no difference in size or germination of the two varieties, the following results obtained: Grown alone, the yields of grain, straw, total crop, and number of culms for Big Frame were respectively 90, 88, 89, and 80 per cent as large as for the Turkey Red. When grown in competition, these Big Frame yields were respectively only 55, 70, 67, and 68 per cent as large as for the Turkey Red.

TABLE 20—*Yields from two varieties of winter wheat when planted alone and in competition. Turkey Red and Big Frame winter wheat (1914)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per 180 seeds	Yield per 180 seeds planted			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE SEED										
Varieties alone										
Turkey Red, large	2.84	1.633	180	83	90	357.9	111.2	375.9	487.1	.30
Big Frame, large	2.71	1.402	180	80	92	308.9	100.6	362.4	463.0	.28
Ratio, B. F. to T. R	.95	.86	1.00	.96	1.02	.86	.90	.96	.95	.93
Varieties competing										
Turkey Red, large	2.84	1.633	90	81.4	90	403.2	120.2	401.4	521.6	.30
Big Frame, large	2.71	1.402	90		92	279.2	71.4	283.6	355.0	.25
Ratio, B. F. to T. R	.95	.86	1.00	....	1.02	.69	.59	.71	.68	.83
SMALL SEED										
Varieties alone										
Turkey Red, small	1.52	.944	180	82	89	374.1	99.9	384.4	484.3	.26
Big Frame, small	1.60	.962	180	79	89	279.6	91.3	311.5	402.8	.29
Ratio, B. F. to T. R	1.05	1.02	1.00	.96	1.00	.75	.91	.81	.83	1.13
Varieties competing										
Turkey Red, small	1.52	.944	90	80.6	89	400.0	116.0	429.2	545.2	.27
Big Frame, small	1.60	.962	90		89	268.2	59.6	301.2	360.8	.20
Ratio, B. F. to T. R	1.05	1.02	1.00	....	1.00	.67	.51	.70	.66	.74
AVERAGE OF RATIOS BETWEEN VARIETIES FOR RECIPROCAL GRADES										
Varieties alone										
Ratio, B. F. to T. R	1.00	.94	1.00	....	1.01	.80	.90	.88	.89	1.03
Varieties competing										
Ratio, B. F. to T. R	1.00	.94	1.00	....	1.01	.68	.55	.70	.67	.78

TABLE 21—*Yields from two varieties of spring wheat when planted alone and in competition (Marquis and Scotch Fife spring wheat, 1914)*

Kind of seed and manner of planting	Seed planted: Weight of 100 seeds	Seed planted: Sprout value of 100 seeds	Seed planted: No. of seeds planted	Germination: Field	Germination: Laboratory	Crop harvested: No. of culms per 180 seeds	Yield per 180 seeds planted: Grain	Yield per 180 seeds planted: Straw	Yield per 180 seeds planted: Total	Yield per 180 seeds planted: Ratio of grain to straw
(1)	*Grams* (2)	*Grams* (3)	(4)	*Per cent* (5)	*Per cent* (6)	(7)	*Grams* (8)	*Grams* (9)	*Grams* (10)	(11)
LARGE SEED										
Varieties alone										
Marquis, large	2.50	1.494	180	64	88	328.0	49.7	336.3	386	.15
Scotch Fife, large	2.49	1.420	180	77	89	328.4	38.0	314.0	352	.12
Ratio, S. F. to M	1.00	.95	1.00	....	1.01	1.00	.76	.93	.91	.80
Varieties competing										
Marquis, large	2.50	1.494	90	77.7	88	301.8	58.0	314.0	372.6	.18
Scotch Fife, large	2.49	1.420	90		89	317.2	35.2	284.6	319.8	.12
Ratio, S. F. to M	1.00	.95	1.00	....	1.01	1.05	.61	.91	.86	.67
SMALL SEED										
Varieties alone										
Marquis, small	1.63	1.035	180	68	87	300.4	43	314.0	357	.14
Scotch Fife, small	1.74	.833	180	74	87	317.8	32	291.0	323	.11
Ratio, S. F. to M	1.07	.80	1.00	....	1.00	1.06	.74	.93	.90	.79
Varieties competing										
Marquis, small	1.63	1.035	90	71	87	286.8	48.8	302.0	350.8	.16
Scotch Fife, small	1.74	.833	90		87	282.8	29.8	270.4	300.2	.11
Ratio, S. F. to M	1.07	.80	1.00	....	1.00	.99	.61	.90	.86	.69
AVERAGE RATIOS BETWEEN VARIETIES FOR RECIPROCAL GRADES										
Varieties alone										
Ratio, S. F. to M	1.03	.87	1.00	....	1.00	1.03	.75	.93	.90	.79
Varieties competing										
Ratio, S. F. to M	1.03	.87	1.00	....	1.00	1.02	.61	.90	.86	.68

TABLE 22—*Yields from two varieties of winter wheat when planted alone and in competition (Turkey Red and Big Frame winter wheat, 1915)*

Kind of seed and manner of planting	Seed planted			Germination		Crop harvested	Yield per 180 seeds planted			
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Field	Laboratory	No. of culms per 180 seeds	Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE SEED										
Varieties alone										
Turkey Red, large	2.66	1.160	180	77.2	85	389	161	453	614	.35
Big Frame, large	2.52	1.015	180	83.8	86	368	142	496	638	.29
Ratio, B. F. to T. R.	.95	.87	1.00	1.09	1.01	.95	.88	1.09	1.04	.83
Varieties competing										
Turkey Red, large	2.66	1.160	90	80	85	322	139	341	480	.24
Big Frame, large	2.52	1.015	90		86	374	161	451	612	.28
Ratio, B. F. to T. R.	.95	.87	1.00	....	1.01	1.16	1.16	1.32	1.27	1.17
SMALL SEED										
Varieties alone										
Turkey Red, small	1.94	.851	180	71.4	80.0	373	169	461	630	.37
Big Frame, small	1.89	.860	180	81.1	80.5	347	128	465	593	.27
Ratio, B. F. to T. R.	.97	1.01	1.00	1.14	1.01	.93	.76	1.01	.94	.73
Varieties competing										
Turkey Red, small	1.94	.851	90	78	80.0	336	122	366	488	.33
Big Frame, small	1.89	.860	90		80.5	396	152	454	606	.33
Ratio, B. F. to T. R.	.97	1.01	1.00	....	1.01	1.18	1.25	1.24	1.24	1.00
AVERAGE OF RATIOS BETWEEN VARIETIES FOR RECIPROCAL GRADES										
Varieties alone										
Ratio, B. F. to T. R.	.96	.94	1.00	....	1.01	.94	.82	1.05	.99	.78
Varieties competing										
Ratio, B. F. to T. R.	.96	.94	1.00	....	1.01	1.17	1.20	1.28	1.25	1.08

TABLE 23—*Yields from two varieties of spring wheat when planted alone and in competition (Marquis and Scotch Fife spring wheat, 1915)*

Kind of seed and manner of planting	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per 180 seeds	Yield per 180 seeds planted			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw
	Grams	*Grams*		*Per cent*	*Per cent*		*Grams*	*Grams*	*Grams*	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
LARGE SEED										
Varieties alone										
Marquis, large	2.41	1.269	180	60.5	82.4	116	65	194	259	.33
Scotch Fife, large	2.37	1.160	180	61.1	79.0	132	63	223	286	.28
Ratio, S. F. to M	.98	.91	1.00	....	.96	1.14	.97	1.15	1.10	.84
Varieties competing										
Marquis, large	2.41	1.269	90	65.5	82.4	112	46	132	178	.35
Scotch Fife, large	2.37	1.160	90		79.0	128	48	176	224	.27
Ratio, S. F. to M	.98	.91	1.00	....	.96	1.14	1.04	1.33	1.26	.78
SMALL SEED										
Varieties alone										
Marquis, small	1.47	.851	180	61.1	81.8	107	53	181	234	.29
Scotch Fife, small	1.70	.755	180	66.1	81.2	111	50	205	255	.24
Ratio, S. F. to M	1.16	.89	1.00	....	.99	1.04	.94	1.13	1.09	.83
Varieties competing										
Marquis, small	1.47	.851	90	70	81.8	100	32	104	136	.31
Scotch Fife, small	1.70	.755	90		81.2	108	30	122	152	.25
Ratio, S. F. to M	1.16	.89	1.00	....	.99	1.08	.94	1.17	1.12	.80
AVERAGE OF RATIOS BETWEEN VARIETIES FOR RECIPROCAL GRADES										
Varieties alone										
Ratio, S. F. to M	1.07	.90	1.00	....	.97	1.09	.95	1.14	1.09	.83
Varieties competing										
Ratio, S. F. to M	1.07	.90	1.00	....	.97	1.11	.99	1.25	1.19	.79

Similar (but less striking) results were obtained in 1914 for Scotch Fife and Marquis spring wheat. When grown alone, the yields of grain, straw, total crop, and number of culms for Scotch Fife were respectively 75, 93, 90, and 103 per cent as large as for the Marquis wheat. In competition, these Scotch Fife yields were respectively 61, 90, 86, and 102 per cent as large as for the Marquis.

Results for 1915—The climatic conditions for 1915 were far different from those in 1914. Practically normal atmospheric and moisture conditions prevailed in 1914. On the other hand, the season of 1915 was unusually cool, humid, and wet. This difference, as has also been observed on other occasions, resulted in a reversal of the competitive qualities of the two varieties.

Planted alone, the yields of grain, straw, total crop, and number of culms for Big Frame winter wheat were respectively 82, 105, 99, and 94 per cent as large as for the Turkey Red. In competition, these Big Frame yields were respectively 120, 128, 125, and 117 per cent as large as for the Turkey Red.

In the test with spring wheat, the yields of grain, straw, total crop, and number of culms for Scotch Fife planted alone were respectively 95, 114, 109, and 109 per cent as large as for the Marquis. In competition, these yields were respectively 99, 125, 119, and 111 per cent as large as for the Marquis.

These investigations suggest that competition may play a very important role in the natural improvement of cereal crops.

RELATION OF SIZE OF SEED TO YIELD OF CEREAL CROPS

METHODS OF INVESTIGATION

Numerous methods of comparing the yielding qualities of seed grades have been employed by the various investigators of this subject. From the standpoint of farm practice the method of comparison should approach normal field conditions as nearly as possible.

Methods of testing grades of seed may be classified as in the following outline:

I. Character of test plat
   1. Small nursery test plats
   2. Large field test plats
   3. Pots filled with soil

II. Manner of planting
   1. Seeds spaced to permit maximum development of individual plants

2. Seeds planted at customary field rate
   (a) Equal numbers of seed planted in a unit area
   (b) Equal weights of seed planted in a unit area
   (c) Equal volumes of seed planted in a unit area

III. Manner of selecting seed grades
   1. Hand selection
   2. Fanning mill separation
   3. Specific gravity separation by salt solution

In the tests which follow, either small nursery test plats or large field plats have been employed. All plats have been planted approximately at the normal field rate, using equal numbers, equal weights, or equal volumes of seed for the various grades. The nursery plats have contained either 1 row, 3 rows, or 5 rows spaced 10 inches apart. Where plats contained 3 or more rows, the 2 outside rows have been discarded, and the yield based upon the remaining rows. Thus competition between the various plats has been avoided. The length of the nursery plats has been either 7½ or 16 feet. The dimensions of the field plats have been 5.33 feet by 16 rods, making 1/30-acre plats. The nursery plats have been replicated from 5 to 10 times each year, while the field plats have been replicated 2, 3, or 4 times in recent years, tho unduplicated in the earlier years. The character of the plat and the number of replications is indicated with each experiment.

The nursery plats have been planted by hand. A press drill was used for seeding the larger field plats.

RELATION OF SIZE OF SEED TO THE YIELD OF WHEAT WHEN THE VARIOUS GRADES ARE PLANTED ALONE IN EQUAL NUMBERS

The unselected seed of 2 winter wheat and 2 spring wheat varieties was compared for yield with large and small seed of the respective varieties during 2 years, 1914 and 1915. Five-row plats 7½ feet long were used. These were replicated 5 times for the winter wheat and 9 times for the spring wheat. The seeds were spaced ½ inch apart, which corresponds to the normal field rate. The results are contained in tables 24 and 25.

As an average for the two varieties of winter wheat, the relative seed weights for the unselected, large, and small seed were respectively 100, 134.6, and 86.9. The corresponding sprout values were 100, 133, and 92.3. The germination for the various grades was fairly uniform. For these grades in the order named, the relative number of culms were 100, 99.9, and 96.4; the relative grain yields were 100, 102.3, and 96.9; the relative straw yields were 100, 99.2, and 96.0; and the relative yields of total dry matter were 100, 100.4, and 96.2. The grain yields of the large seed were 2.3 per cent superior to the unselected seed, while the grain yield from the small seed was 3.1 per cent inferior.

TABLE 24—*Yields from different grades of wheat seed (two-year average, 1914 and 1915)*[1]

Kind of seed planted	Seed planted					Crop harvested				
	Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted	Germination		No. of culms per row	Yield per row			
				Field	Laboratory		Grain	Straw	Total	Ratio of grain to straw[2]
(1)	*Grams* (2)	*Grams* (3)	(4)	*Per cent* (5)	*Per cent* (6)	(7)	*Grams* (8)	*Grams* (9)	*Grams* (10)	(11)
Turkey Red winter wheat										
Unselected	1.83	1.035	180	76.5	84.5	387.7	137.5	424.3	561.8	.32
Large plump	2.75	1.396	180	79.1	87.5	373.4	136.1	414.4	550.5	.32
Small plump	1.73	.897	180	77.2	84.5	373.5	134.4	422.7	557.1	.31
Small shrivelled	1.24	.539	180	71.3	80.7	337.6	131.6	400.2	531.8	.32
Big Frame winter wheat										
Unselected	2.16	.923	180	79.9	85.5	324.5	114.2	420.3	534.5	.27
Large plump	2.61	1.208	180	81.9	89.0	338.4	121.3	429.2	550.5	.28
Small plump	1.74	.911	180	80.0	84.7	313.3	109.6	388.3	497.9	.28
Scotch Fife spring wheat										
Unselected	2.01	1.317	180	71.5	85.2	225.5	44.6	254.3	298.9	.19
Large	2.43	1.290	180	69.0	84.0	230.2	50.5	268.5	319.0	.20
Small	1.72	.794	180	70.0	84.1	214.4	41.0	248.0	289.0	.18
Marquis spring wheat										
Unselected	2.15	1.102	180	60.0	83.9	216.5	51.8	256.2	308.0	.22
Large	2.45	1.381	180	62.2	85.2	222.0	57.3	265.2	322.5	.24
Small	1.55	.943	180	64.5	84.4	203.7	48.0	247.5	295.5	.21

[1]The crop was grown at the ordinary field rate in 5-row nursery plats. Results are based on 3 center rows. The winter wheat plats were replicated 5 times and the spring wheat plats 9 times each year.

[2]Average of ratios for two years.

TABLE 25—*Summary showing yields from different grades of wheat seed (two-year average, 1914 and 1915)*[1]

Kind of seed planted	Seed planted: Weight of 100 seeds	Sprout value of 100 seeds	No. of seeds planted per row	Germination: Field	Germination: Laboratory	Crop harvested: No. of culms per row	Yield per row: Grain	Straw	Total	Ratio of grain to straw
(1)	*Grams* (2)	*Grams* (3)	(4)	*Per cent* (5)	*Per cent* (6)	(7)	*Grams* (8)	*Grams* (9)	*Grams* (10)	(11)
Winter wheat										
(Average Turkey Red and Big Frame)										
ACTUAL RESULTS										
Unselected	1.99	.979	180	78.2	85.0	356.1	125.8	422.3	548.1	.29
Large plump	2.68	1.302	180	80.5	88.2	355.9	128.7	421.8	550.5	.30
Small plump	1.73	.904	180	78.6	84.6	343.4	122.0	405.5	527.5	.30
RELATIVE RESULTS BASED ON UNSELECTED SEED	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Unselected	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Large plump	134.6	133.0	100.0	102.9	103.7	99.9	102.3	99.9	100.4	103.4
Small plump	86.9	92.3	100.0	100.5	99.5	96.4	96.9	96.0	96.2	103.4
Spring wheat										
(Average Scotch Fife and Marquis)										
ACTUAL RESULTS	*Grams*	*Grams*	*Number*	*Per cent*	*Per cent*	*Number*	*Grams*	*Grams*	*Grams*	*Grams*
Unselected	2.08	1.209	180	65.7	84.5	221.0	48.2	255.2	303.4	.21
Large	2.44	1.335	180	65.6	84.6	226.0	53.9	266.8	320.7	.22
Small	1.63	.868	180	67.2	84.2	209.0	44.5	247.7	292.2	.20
RELATIVE RESULTS BASED ON UNSELECTED SEED	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Unselected	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Large	117.3	110.4	100.0	99.8	100.0	102.3	111.8	104.5	105.7	104.8
Small	78.4	71.8	100.0	102.2	99.6	94.6	92.3	97.0	96.3	95.2

[1]Data calculated from table 24.

The average germination of the two spring wheat varieties was quite uniform for the three grades of unselected, large, and small seed. The relative seed weights were respectively 100, 117.3, and 78.4, while the corresponding sprout values were 100, 110.4, and 71.8. The germination for the various grades was fairly uniform. The relative numbers of culms were respectively 100, 102.3, and 94.6; the relative grain yields were 100, 111.8, and 92.3; the relative straw yields were 100, 104.5, and 97.0; and the relative yields of total dry matter were 100, 105.7, and 96.3. With the spring wheat, the large seed outyielded the unselected for grain 11.8 per cent, while the grain yield of the small seed was 7.7 per cent inferior to the unselected seed.

The summary results for both winter wheat and spring wheat (table 25) indicate a distinct advantage for the large as compared with the unselected seed. This advantage is greater for the spring wheat, which may be due to the fact that it is a more poorly adapted crop than the winter wheat. Because of a longer growing season and more favorable early growth conditions for winter than for spring wheat, the initial advantage of the large seed is less marked for the winter than for the spring wheat.

WHY SMALL SEEDS YIELD LESS PER ACRE THAN LARGE SEEDS WHEN PLANTED IN EQUAL NUMBERS AT THE NORMAL RATE FOR THE LARGE SEED

Thruout all of the comparative yield tests for large and small seeds reported in this paper, the large seeds have given a greater yield than the small seeds when planted in equal numbers at the normal rate for the large seed.

While there has been a slight reduction in field germination for the small seeds in some instances, this decrease has not been relatively as great as the decrease in yield. In order to determine whether the characters of growth differed for the individual plants grown from large and small seeds, such grades of Scotch Fife and Marquis spring wheat and Kherson oats were space-planted 6 by 10 inches apart and grown to maturity in 1916. This plan permitted maximum development for the plants. The differences in resulting growth may be attributed to the size of seed rather than to any environmental differences. The results follow in table 26.

As an average for the spring wheat and oats, the small seeds planted weighed 52 per cent as much as the large seed. With the individual plant of the resulting crop, the small seed compared with the large produced 80 per cent as many culms per plant; 72 per cent as high grain yield; 77 per cent as great straw yield; and 77 per cent as great total yield. This inferiority of individual plant development from small seeds may account for the smaller

TABLE 26—*Relative development and yield of plants from large and small seed when space-planted to permit maximum development (1916)*[1]

Kind of seed planted	Number of plants averaged	Weight of 100 seeds planted	Results per 100 plants: Number of culms	Results per 100 plants: Yield of grain	Results per 100 plants: Yield of straw	Results per 100 plants: Total yield
		Grams		*Grams*	*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Scotch Fife Sp. wheat, large	300	3.07	833	9.3	79.5	88.8
Scotch Fife Sp. wheat, small	298	1.85	670	6.5	59.8	66.3
Marquis Sp. wheat, large	218	3.04	800	11.1	96.4	107.5
Marquis Sp. wheat, small	181	1.61	590	6.6	69.5	76.1
Kherson oats, large	433	2.25	920	46.1	91.0	137.1
Kherson oats, small	408	1.00	790	40.7	75.2	115.9
RELATIVE RESULTS BASED ON LARGE SEED						
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Scotch Fife Sp. wheat, large	....	100	100	100	100	100
Scotch Fife Sp. wheat, small	....	60	80	70	75	75
Marquis Sp. wheat, large	....	100	100	100	100	100
Marquis Sp. wheat, small	....	53	74	59	72	71
Kherson oats, large	....	100	100	100	100	100
Kherson oats, small	....	44	86	88	83	85
Average for Sp. wheat and oats, large	....	100	100	100	100	100
Average for Sp. wheat and oats, small	....	52	80	72	77	77

[1]The plants were spaced 6 inches apart in rows 10 inches apart.

yields obtained from small seed when planted in equal numbers to the large. On the other hand this lower productiveness of the individual plant is unimportant, as shown in the following investigation, when a greater number of plants from small seed are secured by planting equal weights of seed.

RELATIVE YIELDS FROM LARGE AND SMALL SEEDS OF CEREALS WHEN PLANTED IN EQUAL NUMBERS AND AT EQUAL WEIGHTS

An investigation was started with winter wheat in 1911 to determine the relative yields of unselected, large, and small seeds of cereal crops, when compared in equal numbers and equal weights of seeds planted. This test has been continued ever since, except during 1912 and 1913, in which years the crops were lost, by winterkilling in 1912 and by excessive lodging and rusting in 1913 owing to planting on summer-fallowed land. The experiment has been repeated with Kherson oats during the 5 years 1912 to 1916 and with spring wheat in 1915 and 1916.

The test plats contained three 16-foot rows spaced 8 inches apart, with the exception that the 1912 and 1913 oat tests and the 1911 winter wheat tests were conducted in 1-row plats.

The large seeds were in all cases spaced in the row at approximately the normal field rate of planting. Other grades were planted in both equal numbers and equal weights to this. The planting plans are shown in figures 6 and 7. The results are given in tables 27 to 29 and are summarized in table 30.

Winter wheat, 4-year average—Planted in equal numbers, the small seed yielded 4 per cent less than the large seed, while the yields of large and small seed were equal when equal weights of seed were planted. The small seed sown in equal numbers weighed only 62 per cent as much as the large, while in equal weights the number of small seed exceeded the large 80 per cent. The unselected seed yielded 1 per cent less than the large when equal numbers of seeds were sown, and 5 per cent more when equal weights of seed were used.

(a)	Large seed
(b)	Small seed, equal numbers to (a)
(c)	Unselected seed, equal numbers to (a)
(d)	Small seed, equal weights to (a)
(e)	Unselected seed, equal weights to (a)

Fig. 6—Plan for planting winter wheat tests. The entire series was repeated 10 times each year

(a)	Large seed
(b)	Unselected seed, equal weights to (a)
(c)	Small seed, equal numbers to (a)
(d)	Unselected seed, equal weights to (a)
(e)	Small seed, equal weights to (a)
(f)	Unselected seed, equal weights to (a)

Fig. 7—Plan for planting oats and spring wheat tests. The entire series was repeated 10 times each year

Oats, 4-year average—The small seed yielded 11 per cent less than the large when sown in equal numbers, and both yielded alike when equal weights of seed were used. The unselected seed yielded 2 per cent less than the large or small where equal weights of seed were used.

TABLE 27—*Yields from equal numbers versus equal weights of large and small seed of Turkey Red winter wheat (1911, 1914, 1915, and 1916)*[1]

Kind of seed planted	Equal numbers of seed			Equal weights of seed		
	Number of seed planted	Weight of seed planted	Yield per row	Number of seed planted	Weight of seed planted	Yield per row
		Grams	*Grams*		*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
YEAR 1911						
Large	400	14.00	440	400	14.0	440
Small	400	10.04	422	560	14.0	446
Unselected	400	12.30	435	455	14.0	469
YEAR 1914						
Large	400	11.70	221	400	11.7	221
Small	400	6.70	211	700	11.7	243
Unselected	400	9.30	255	503	11.7	248
YEAR 1915						
Large	404	11.70	363	404	11.7	363
Small	404	7.60	355	818	11.7	327
Unselected	404	9.60	337	525	11.7	365
YEAR 1916						
Large	400	9.90	417	400	9.9	417
Small	400	5.15	388	807	9.9	422
Unselected	400	7.55	396	547	9.9	426
FOUR-YEAR AVER'GE						
Large	400	11.82	360	401	11.8	360
Small	400	7.37	344	721	11.8	360
Unselected	400	9.69	356	508	11.8	377

[1]The tests were made in single-row plats in 1911 and in 3-row blocks in 1914, 1915, and 1916. Results are based on the center row of 3-row plats. All plats were replicated 10 times each year.

TABLE 28—*Yields from equal numbers versus equal weights of large and small seed of Kherson oats (1912 to 1916)*[1]

Kind of seed planted	Equal numbers of seed			Equal weights of seed		
	Number of seed planted	Weight of seed planted	Yield per row	Number of seed planted	Weight of seed planted	Yield per row
		Grams	*Grams*		*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
YEAR 1912						
Large	404	10.15	113	404	10.15	113
Small	404	6.99	106	587	10.15	105
Unselected	....	....	....	500	10.15	110
YEAR 1913						
Large	404	8.96	318	404	8.96	318
Small	404	4.68	245	750	8.96	339
Unselected	....	....	....	541	8.96	320
YEAR 1914						
Large	404	7.59	118	404	7.59	118
Small	404	4.80	120	643	7.59	110
Unselected	....	....	....	506	7.59	111
YEAR 1915						
Large	400	9.1	151	400	9.10	151
Small	400	4.8	148	759	9.10	170
Unselected	....	....	....	530	9.10	160
YEAR 1916						
Large	400	8.51	326	400	8.51	326
Small	400	3.88	291	878	8.51	302
Unselected	....	....	....	625	8.51	306
FIVE-YEAR AVERAGE						
Large	402	8.86	205	402	8.86	205
Small	402	5.03	182	723	8.86	205
Unselected	....	....	....	550	8.86	201

[1]The tests were made in single-row plats in 1912 and 1913 and in 3-row blocks in 1914, 1915, and 1916. Results are based on the center row of 3-row blocks.

All tests were replicated 10 times each year, except the unselected seed which was repeated 30 times.

The small seed sown in equal numbers weighed 57 per cent as much as the large, while in equal weights the number of small seed exceeded the large 80 per cent.

Spring wheat, 2-year average—When sown in equal numbers, the small seed yielded 10 per cent less than the large seed, while it yielded 1 per cent less when equal weights of seed were sown. The unselected seed yielded 8 per cent more than the large when sown in equal weights.

The small seed sown in equal numbers weighed 53 per cent as much as the large, while in equal weights the number of small seeds exceeded the large 93 per cent.

TABLE 29—*Yields from equal numbers versus equal weights of large and small seed of Scotch Fife spring wheat (1915 and 1916)*[1]

Kind of seed planted	Equal numbers of seed			Equal weights of seed		
	Number of seed planted	Weight of seed planted	Yield per row	Number of seed planted	Weight of seed planted	Yield per row
		Grams	*Grams*		*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
YEAR 1915						
Large	450	11.30	103.2	450	11.30	103.2
Small	450	5.30	103.0	959	11.30	110.0
Unselected	....	....	....	610	11.30	122.6
YEAR 1916						
Large	400	11.04	131.8	400	11.04	131.8
Small	400	6.65	109.0	680	11.04	121.4
Unselected	....	....	....	502	11.04	130.8
TWO-YEAR AVERAGE						
Large	425	11.17	117.5	425	11.17	117.5
Small	425	5.98	106.0	820	11.17	115.7
Unselected	....	....	....	556	11.17	126.7

[1]All tests were replicated 10 times each year, except the original seed, which was repeated 30 times. Yields are based on center row of 3-row blocks.

TABLE 30—*Relative results with large and small seeds when compared by planting equal numbers versus equal weights*[1]

Kind of seed planted	Equal numbers of seed			Equal weights of seed		
	Number of seed planted	Weight of seed planted	Yield per row	Number of seed planted	Weight of seed planted	Yield per row
		Grams	*Grams*		*Grams*	*Grams*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
TURKEY RED WINTER WHEAT—4-YEAR AVERAGE						
Large	100	100	100	100	100	100
Small	100	62	96	180	100	100
Unselected	100	82	99	126	100	105
KHERSON OATS—5-YEAR AVERAGE						
Large	100	100	100	100	100	100
Small	100	57	89	180	100	100
Unselected	....	....	....	137	100	98
SCOTCH FIFE SPRING WHEAT—2-YEAR AVERAGE						
Large	100	100	100	100	100	100
Small	100	53	90	193	100	99
Unselected	....	....	....	131	100	108

[1]Compiled from tables 27 to 29.

In general, it may be concluded from these tests that it is of vital consideration whether equal weights or equal numbers of seeds are planted in a comparison of the yields from large and small seed. For the three cereals tested, the small seed yielded on an average only $\frac{1}{3}$ of one per cent less than the large seed when equal weights of seed were sown. However, when planted in equal numbers, the small seed yielded an average of 8 per cent less.

Planting the seed in equal weights corresponds far more nearly to farm practice than does seeding in equal numbers.

RELATIVE YIELDS OF SEED GRADES OF WHEAT AND OATS AS SEPARATED BY FANNING MILL

The investigations regarding the use of the fanning mill reported in this bulletin are a continuation of earlier studies by Lyon and Montgomery at this Station prior to their removal to Cornell University. Lyon (1902) reported two years' effect from the use of the fanning mill upon the wheat yield. In 1905 Lyon reported two additional years' studies along the same line. Montgomery (1908) reported results with wheat and oats continued after the same plan.

The tables which follow contain all of the data obtained since 1907, and have been heretofore unpublished.

The separation of the wheat or oats into light and heavy seed has been accomplished by the use of a machine producing a regulated, upward wind blast. The grain was directed into this blast which carried out the lightest one-half of the seed, while the heavier seed fell against the air blast into a box below. Both grades of seed were again separated in the same manner, resulting in two grades known as the lightest one-fourth and the heaviest one-fourth. Each grade has been constantly continued in like manner. The lightest one-fourth has each year been taken from the preceding crop grown from the lightest one-fourth. In turn the heaviest one-fourth has consecutively been taken from the preceding crop grown from the heaviest one-fourth. Thus an opportunity has been afforded for an accumulative effect of the fanning process. The results for two varieties each of winter wheat and oats are given in tables 31 to 36.

Wheat—The two grades of seed have been compared each year with the original unselected seed. Two varieties, Turkey Red and Big Frame, have been used in this test during a period of 12 years, 1900-1911.

The wheat has been sown thruout this period with a grain drill set at the rate of 5 pecks per acre for all grades. The results are given in tables 31 and 32.

TABLE 31—*Yields of light and heavy seed wheat as separated by a fanning mill (1900 to 1911)*

Kind of seed planted	Yield per acre												
	1900	1901	1902	1903	1904[1]	1905	1906	1907	1908	1909	1910	1911	Average 12 years
(1)	*Bus.* (2)	*Bus.* (3)	*Bus.* (4)	*Bus.* (5)	*Bus.* (6)	*Bus.* (7)	*Bus.* (8)	*Bus.* (9)	*Bus.* (10)	*Bus.* (11)	*Bus.* (12)	*Bus.* (13)	*Bus.* (14)
TURKEY RED WHEAT													
Original unselected	27.5	26.0	17.8	31.8	14.3	20.5	63.0	51.0	28.3	34.5	46.0	51.8	34.4
Heaviest one-fourth	29.3	29.3	18.8	33.0	11.6	20.7	61.6	53.5	32.2	34.1	48.8	51.4	35.4
Lightest one-fourth	23.0	26.7	24.6	30.0	15.6	23.2	62.5	51.0	26.8	37.9	48.5	50.8	35.1
Number of plats averaged	1	1	1	1	1	1	1	1	1	1	2	3	
BIG FRAME WHEAT													
Original unselected	25.8	25.8	11.5	27.3	12.5	20.5	54.6	50.0	35.2	32.5	45.9	49.3	32.6
Heaviest one-fourth	25.0	27.7	4.8	20.8	17.5	25.0	54.8	50.0	34.5	33.8	45.4	49.1	32.4
Lightest one-fourth	20.5	21.2	8.0	25.8	12.3	19.7	50.5	50.0	35.3	32.9	46.5	48.3	31.0
Number of plats averaged	1	1	1	1	1	1	1	1	1	1	2	3	

[1]Owing to extremely poor seed in 1904, no separation was made, but the wheat from each plat was simply cleaned and sown.

TABLE 32—*Weight per bushel of crop harvested from light and heavy wheat seed as separated by a fanning mill (1902 to 1911)*

Kind of seed planted	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	Average
(1)	*Pounds* (2)	*Pounds* (3)	*Pounds* (4)	*Pounds* (5)	*Pounds* (6)	*Pounds* (7)	*Pounds* (8)	*Pounds* (9)	*Pounds* (10)	*Pounds* (11)	*Pounds* (12)
TURKEY RED WINTER WHEAT											
Original unselected	57.0	....	44.0	62.0	61.0	60.0	54.5	61.0	....	63.0	57.8
Heaviest one-fourth	56.0	....	44.3	61.0	61.0	60.0	54.0	61.0	....	62.7	57.5
Lightest one-fourth	60.0	....	42.5	62.0	61.0	61.0	55.5	59.0	....	62.8	58.0
BIG FRAME WINTER WHEAT											
Original unselected	55.5	....	39.5	59.0	60.5	59.0	54.0	59.5	....	62.0	56.1
Heaviest one-fourth	52.5	....	46.5	60.0	61.5	59.0	57.0	60.5	....	62.8	57.5
Lightest one-fourth	55.5	....	42.5	58.5	61.0	59.0	54.0	59.5	....	62.5	56.5

TABLE 33—*Yields of light and heavy seed of Kherson oats as separated by a fanning mill (1905 to 1916)*

Kind of seed planted	Yield per acre												
	1905	1906	1907	1908[1]	1909	1910	1911	1912	1913	1914	1915	1916	Average 12 years
	Bus.	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Original unselected	88.4	58.1	49.8	49.1	66.2	38.2	40.6	50.9	42.6	56.4	30.0	85.8	54.62
Heaviest one-fourth	91.0	58.4	49.0	52.0	64.0	38.6	37.0	51.6	48.0	58.7	31.4	85.7	55.45
Lightest one-fourth	90.1	59.5	43.8	49.1	65.6	37.5	37.4	48.8	51.4	61.6	25.8	86.7	54.71
Number of plats averaged	2	2	2	2	2	2	2	2	4	3	2	2	

[1]Continuous selection since 1908.

TABLE 34—*Weight per bushel of crop harvested from light and heavy seed of Kherson oats as separated by a fanning mill (1905 to 1916)*

Kind of seed planted	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	Average
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Original unselected	....	35.0	29.2	23.2	26.5	31.0	34.0	25.0	28.5	23.2	21.2	30.0	27.9
Heaviest one-fourth	....	35.0	29.6	24.5	26.5	31.0	34.0	25.0	26.8	25.7	24.0	33.0	28.6
Lightest one-fourth	....	34.5	28.5	24.5	26.2	31.0	34.0	24.0	26.3	23.5	20.5	31.5	27.4

TABLE 35—*Yields of light and heavy seed of American Banner oats as separated by a fanning mill (1909 to 1916)*

Kind of seed planted	Yield per acre									
	1909	1910	1911	1912	1913	1914	1915	1916	Average 8 years	Average last 4 years
(1)	*Bushels* (2)	*Bushels* (3)	*Bushels* (4)	*Bushels* (5)	*Bushels* (6)	*Bushels* (7)	*Bushels* (8)	*Bushels* (9)	*Bushels* (10)	*Bushels* (11)
Original unselected	....	....	....	....	30.0	45.4	22.1	69.6	....	41.77
Heaviest one-fourth	58.8	47.9	35.4	32.8	29.7	39.0	24.2	65.8	41.74	39.70
Lightest one-fourth	58.2	50.2	29.8	33.3	32.3	45.7	21.1	74.5	43.17	43.37
Number of plats averaged	2	2	2	2	4	3	2	2		

TABLE 36—*Weight per bushel of crop harvested from light and heavy seed of American Banner oats as separated by a fanning mill (1909 to 1916)*

Kind of seed planted	1909	1910	1911	1912	1913	1914	1915	1916	Average for 8 years	Average for 4 years
(1)	*Pounds* (2)	*Pounds* (3)	*Pounds* (4)	*Pounds* (5)	*Pounds* (6)	*Pounds* (7)	*Pounds* (8)	*Pounds* (9)	*Pounds* (10)	*Pounds* (11)
Original unselected	....	....	....	....	27.5	26.2	21.2	31.0	....	26.5
Heaviest one-fourth	29.5	31.5	26.5	22.0	28.0	20.7	19.5	30.0	25.9	24.5
Lightest one-fourth	28.2	31.5	23.5	22.0	27.7	23.0	20.7	30.7	25.9	25.5

As an average for both varieties during 12 years, the light seed has yielded 0.5 bushel less than the unselected seed, while the heavy seed has yielded 0.4 bushel more than the unselected.

The average weights per bushel for crop harvested from the three grades have been 56.9, 57.5, and 57.3 pounds respectively for the unselected, heavy, and light seed.

Oats—The fanning mill tests with oats seed have been conducted with two varieties—Kherson and American Banner. The general plan was the same as for the wheat. All grades of Kherson oats have been planted at the standard rate of 10 pecks per acre, by means of a press drill. Since American Banner is a larger seeded variety, the drill was set at 12 pecks for all grades.

The Kherson oat tests have extended from 1905 to 1916, giving 12 years' results. The light seed has yielded 0.09 bushel more and the heavy seed 0.83 bushel more than the unselected seed. The average weight per bushel of crop harvested has been 27.9, 28.6, and 27.4 pounds respectively for the unselected, heavy, and light grades.

The tests with American Banner oats have continued since 1909. The unselected seed has been included only since 1913.

The yields indicate that this variety was to begin with a mixture of types. The crop from the light seed has also been slightly earlier during each of the past 4 years—the average time of heading being 2 days earlier than for the crop from the heavy seed. As a result of the fanning mill separation, the lightest one-fourth of the seed has produced 1.43 bushels greater yield than the heavy seed as an average for 8 years. During the last 4 years in which the original unselected seed was also grown, the light seed has yielded 3.67 bushels more than the heavy seed, and 1.6 bushels more than the original unselected seed. The average respective weights per bushel for the crop harvested from the unselected, heavy, and light seed have been 26.5, 24.5, and 25.5 pounds.

To sum up, the superiority in yield of heavy seed over the unselected seed has been 0.83 bushel per acre for Turkey Red winter wheat and 1 bushel for Kherson oats. On the other hand, the heavy seed of Big Frame wheat has yielded 0.2 bushel less than the original unselected seed, and for American Banner oats the heavy seed has yielded 2.07 bushels less.

The lightest one-fourth of the Turkey Red and of the Big Frame seed have yielded respectively 0.7 bushel more and 1.6 bushels less than the unselected seed.

The lightest one-fourth Kherson oats yielded 0.09 bushel more than the unselected seed, while the light American Banner yielded 1.6 bushels more than the unselected seed. As the result

of 12 years of continuous use of the fanning mill in securing the heaviest one-fourth of the seed each year for planting, no definite appreciable improvement has been effected.

HISTORICAL SUMMARY OF INVESTIGATIONS WITH GRADES OF SMALL GRAIN SEEDS

Numerous tests have been made comparing the yielding qualities of large and small or light and heavy seeds. Various methods of testing have been employed by the various investigators and the results are not all directly comparable with one another.

The separations have been made in part by the use of hand screens. In other experiments, some form of fanning mill has been employed. Again, part of the grades have been separated by hand selection of large and small seeds. The outcome of all methods was to secure distinct grades of seed, altho the most clearly defined and uniform grades were doubtless secured by the hand selection.

Some of the experiments have been made in large field plats, while others have been made in small nursery plats. The small nursery plats are regarded as quite reliable if sufficiently replicated. Some investigations have extended over a period of years, while others are of only a single year duration. In some, replication of plats has been practiced and in others not. In a number of cases, the tests have been made in pots under laboratory conditions. Several experiments also report the relative yields of large and small seed when grown alone and when grown in competition with each other.

The various grades under comparison have also been planted in equal numbers, equal weights, and equal volumes, at the normal rates for the large seed. In several tests they have been space-planted to permit maximum development of the individual plant.

In some investigations, continuous selection has been practiced by taking seed of a given grade each year from the crop grown from that same grade the previous year. This would permit an accumulative effect.

Some experiments have compared only large and small seed, while others have also included the original unselected seed in the test.

All of these conditions, as far as they are reported in bulletins, together with the yields obtained, have been summarized briefly in tables 37 and 38. Tables 39 to 45 are general compilations from tables 37 and 38, secured in some instances by averaging data given by the investigator to fit the particular requirements of the table.

TABLE 37—*Historical summary of small grain yield tests with different grades of seed. Yields based on small areas*

Crop used	Investigator	Date of publication	Method of conducting test		Duration of experiment	Character of seed	Yield
					Years		*Bushels*
SEED HAND SELECTED. NORMAL NUMBER OF SEED PLANTED. YIELD IN BUSHELS PER ACRE							
Winter wheat	Kiesselbach, T. A.,[1] and Helm, C. A	1917	Hand screens	Not continuous Plats repeated 5 times Average of 2 varieties	2	Original Large, plump Small, plump	40.2 41.1 39.0
Winter wheat	Montgomery, E. G.[1]	1912	Hand selection	Not continuous Plats repeated	1	Large Small	47.17 43.81
Winter wheat	Soule, A. M., and Vanatter, P. O	1903	Hand screens	Not duplicated	3	Large Small	28.6 23.42
Winter wheat	Zavitz, C. A	1907	Hand screens	Not continuous Not duplicated	6	Large, plump Small, plump	46.9 40.4
Spring wheat	Kiesselbach, T. A.,[1] and Helm, C. A	1917	Hand screens	Not continuous Plats repeated 9 times Average of 2 varieties	2	Original Large Small	15.4 18.3 14.2
Spring wheat	Zavitz, C. A	1907	Hand screens	Not continuous Not duplicated	8	Large, plump Small, plump	21.7 18
Oats	Montgomery, E. G.[1]	1912	Hand selection	Not continuous Plats repeated	1	Large Small	48.32 43.85
Oats	Zavitz, C. A	1908	Hand selection	Not continuous Not duplicated	7	Large Medium size Small	62 54.1 46.6
Oats	Zavitz, C. A	1908	Hand selection	Continuous Not duplicated	12	Large, black-colored Small, light-colored	70.5 53.86
Barley	Soule, A. M., and Vanatter, P. O	1901	Hand screens	Not duplicated	1	Large Small	36.3 28.7
Barley	Zavitz, C. A	1907	Hand selection	Not continuous	6	Large, plump Small, plump	53.8 50.4
Rye	Nielson, P	1895	Hand screens	Not continuous	4	Large, plump Next to large Next to small Small	26.6 26.8 25.8 25.6

[1] Yields calculated from grams to bushels per acre.

TABLE 37 *Continued—Historical summary of small grain yield tests with different grades of seed. Yields based on small areas*

Crop used	Investigator	Date of publication	Method of conducting test		Duration of experiment	Character of seed		Yield
					Years			*Bushels*
SEED PLANTED AT NORMAL RATE. EQUAL WEIGHTS VERSUS EQUAL NUMBERS. YIELD IN BUSHELS PER ACRE								
Winter wheat	Kiesselbach, T. A., and Helm, C. A.	1917	Hand selection	Not continuous Plats replicated 10 times	4	Equal numbers	Large	43.2
							Small	41.3
						Equal weights	Large	43.2
							Small	43.2
Oats	Kiesselbach, T. A., and Helm, C. A., also Kiesselbach, T. A., and Ratcliff, J. A.	1917	Hand selection	Not continuous Plats replicated 10 times	5	Equal numbers	Large	46.1
							Small	41
						Equal weights	Large	46.1
							Small	46.1
Spring wheat	Kiesselbach, T. A., and Helm. C. A.	1917	Hand selection	Not continuous Plats replicated 10 times	2	Equal numbers	Large	14.1
							Small	12.7
						Equal weights	Large	14.1
							Small	13.9
SEED HAND SELECTED, SPACE-PLANTED. RELATIVE YIELDS								*Per cent*
Winter wheat	Cobb, N. A.	1903	Hand screens	Not duplicated	3	Large, plump		100
						Small, shrivelled		83
Spring wheat	Bolley, H. L.	1901	Hand selection	Not duplicated	4	Large, plump		100
						Small, plump		90
Spring wheat	Kiesselbach, T, A., and Helm, C. A.	1917	Hand selection	Average of 2 varieties Plats replicated 10 times	1	Individual plant yields	Large	100
							Small	64
Oats	Kiesselbach, T. A., and Helm, C. A.	1917	Hand selection	Plats replicated 10 times	1	Individual plant yields	Large	100
							Small	84
Oats	Williams, C. G., and Welton, F. A.	1913	Hand selection	Not continuous Plats repeated	5	Primary seed		100
						Secondary seed		94

TABLE 37 *Continued—Historical summary of small grain yield tests with different grades of seed. Yields based on small areas*

Crop used	Investigator	Date of publication	Method of conducting test		Duration of experiment	Character of seed	Yield
					Years		
SEED HAND SELECTED. PLANTS GROWN IN POTS, EQUAL NUMBERS. YIELD IN GRAMS PER POT							
Winter wheat	Voelcker, J. A	1902	Hand selection	Two varieties averaged Duplicated	1	Large Small	10.34 11.14
Winter wheat	Voelcker, J. A	1903	Hand selection	Two varieties averaged Duplicated	1	Large Small	19.48 19.53
Winter wheat	Williams, C. G	1905	Hand selection	Seed selected from same heads	1	Large Small	13.21 15.68
RELATIVE YIELDS OF LARGE AND SMALL SEED WHEN PLANTED AT THE ORDINARY FIELD RATE IN EQUAL NUMBERS ALONE AND IN COMPETITION WITH EACH OTHER IN THE ROW							
Wheat	Kiesselbach, T. A., and Helm, C. A	1917	Hand selection	Not continuous Average for fall and spring wheat Plats replicated 5—9 times	2	Alone { Large Alone { Small Competition { Large Competition { Small	100 89 100 76
Oats	Montgomery, E. G	1912	Hand selection	Not continuous Plats duplicated	1	Alone { Large Alone { Small Competition { Large Competition { Small	100 93 100 80

TABLE 38—*Historical summary showing effect of fanning mill separation upon the seed value of small grains when planted under farm conditions*

Crop used	Investigator	Date of publication	Method of conducting test		Duration of experiment	Character of seed	Yield per acre
					Years		*Bushels*
Winter wheat	Georgeson, C. C.	1896	Fanning mill and screens	Not continuous Plats repeated 5 times	4	Common Heavy Light	28.97 29.15 27.6
Winter wheat	Grenfall, C. N	1901	Fanning mill and screens	Average of 2 varieties Average of 6 plats	1	Plump Shrivelled	9.7 7.5
Winter wheat	Kiesselbach, T. A., and Helm, C. A.	1917	Wind blast	Continuous selection Average of 2 varieties Plats duplicated in part	12	Check Heaviest one-fourth. Lightest one-fourth	33.5 33.9 33
Winter wheat	Hickman, J. F	1897	Fanning mill and screens	Continuous selection Average of 3 varieties	4	Unscreened First grade Second grade	13.37 14 13.74
Winter wheat	Hickman, J. F	1901	Fanning mill and screens	Continuous selection Average of 3 varieties	9	Unscreened First grade Second grade	16.33 17.06 16.21
Winter wheat	Lyon, T. L.[1]	1905	Wind blast	Not continuous Not duplicated	4	Heavy Light	24.5 23.7
Winter wheat	Latta, W. C	1891	Fanning mill and screens	Not continuous Large seed duplicated	3	Large Small	30.54 27.94
Winter wheat	Montgomery, E. G.	1908	Wind blast	Continuous selection Average of 2 varieties Not duplicated	8	Ordinary Heaviest heavy Lightest light	30 30.2 29
Winter wheat	Sanborn, J. W	1893	Fanning mill	Not continuous	4	Ordinary Big Medium size Small Smallest	16.42 18.72 16.6 18.72 11.25
Winter wheat	Williams, C. G.	1905	Fanning mill and screens	Not continuous	2	First grade Second grade Third grade	22.64 22.58 21.77
Winter wheat	Williams, C. G., and Welton, F. A.	1911	Fanning mill and screens	Continuous Plats repeated	7	First grade Second grade Third grade	31.26 31.4 31.25

[1]Yields averaged from data given in bulletin.

TABLE 38 *Continued—Historical summary showing effect of fanning mill separation upon the seed value of small grains when planted under farm conditions*

Crop used	Investigator	Date of publication	Method of conducting test		Duration of experiment	Character of seed	Yield per acre
					Years		*Bushels*
Oats	Burnett, L. C.	1912	Fanning mill	Not continuous Average of 2 varieties Duplicated	3	Not fanned Fanned 1 time Fanned 2 times Fanned 3 times	48.5 49 49.7 48.3
Oats	Boss, A.	1893	Fanning mill	Not continuous	1	Heavy Light	64.09 54.59
Oats	Georgeson, C. C.	1897	Fanning mill	Continuous Plats repeated 5 times	8	Common Heavy Light	29.89 30.9 27.5
Oats (Kherson)	Kiesselbach, T. A., and Ratcliff, J. A.	1917	Wind blast	Continuous since 1907 Plats repeated	12	Check Heaviest one-fourth Lightest one-fourth	54.62 55.45 54.71
Oats (American Banner)	Kiesselbach, T. A., and Ratcliff, J. A.	1917	Wind blast	Continuous Plats repeated	4	Unselected Heaviest one-fourth Lightest one-fourth	41.77 39.7 43.37
Oats	Williams, C. G., and Welton, F. A.	1913	Wing blast and screens	Continuous Duplicated	4	Unselected Heavy Light	58.23 58.98 56.66
Oats	Montgomery, E. G.	1908	Wind blast	Continuous	3	Check Heaviest heavy Lightest heavy Heaviest light Lightest light	65.4 66.1 65.6 64.1 64.5
Oats	Williams, C. G.	1903	Fanning mill	Not continuous	7	Common Heavy Light	44.77 46.31 42.63
Rye	Nielson, P.	1895	Fanning mill	Not continuous Plats repeated	7	Large Next to large Next to small Small	37.8 38.5 39.1 38.5
Barley	Voelcker, J. A.	1906	Fanning mill and screens	Not continuous	1	Large Small	3[illegible].1 36.4

TABLE 39—*Relative yields of large and small seeds, space-planted to permit maximum individual plant development*

Crop	Investigator	Date of publication	Duration of test	Relative yields: Large seed	Relative yields: Small seed
			Years	*Per cent*	*Per cent*
Winter wheat	Cobb, N. A	1903	3	100	83
Spring wheat	Bolley, H. L	1901	4	100	90
Spring wheat	Kiesselbach, T. A., and Helm, C. A	1917	1	100	64
Oats	Kiesselbach, T. A., and Helm, C. A	1917	1	100	84
Oats	Williams, C. G., and Welton, F. A	1913	5	100	94
		Average		100	83

TABLE 40—*Relative yields of large and small seeds when planted in equal numbers in pots*

Crop	Investigator	Date of publication	Duration of test	Yield per acre: Large seed	Yield per acre: Small seed	Ratio, small to large
			Years	*Bushels*	*Bushels*	
Winter wheat	Voelcker, J. A	1902	1	10.34	11.14	1.08
Winter wheat	Voelcker, J. A	1903	1	19.48	19.53	1.00
Winter wheat	Williams, C. G	1905	1	13.21	15.68	1.19
		Average		14.34	15.45	1.09

TABLE 41—*Relative yields from large and small seeds when planted in equal numbers at a rate normal for the large seeds*

Crop	Investigator	Date of publication	Duration of test	Yield per acre		Ratio, small to large
				Large or heavy seed	Small or light seed	
			Years	*Bushels*	*Bushels*	
Winter wheat	Kiesselbach, T. A., and Helm, C. A	1917	2	41.1	39.00	.95
Winter wheat	Montgomery, E. G	1912	1	47.17	43.81	.93
Winter wheat	Soule, A. M., and Vanatter, P. O	1903	3	26.60	23.42	.88
Winter wheat	Zavitz, C. A	1907	6	46.90	40.40	.86
Spring wheat	Kiesselbach, T. A., and Helm, C. A	1917	2	18.30	14.20	.78
Spring wheat	Zavitz, C. A	1907	8	21.70	18.00	.83
Oats	Montgomery, E. G	1912	1	48.32	43.85	.91
Oats	Zavitz, C. A	1908	7	54.10	46.60	.86
Oats	Zavitz, C. A	1908	12	70.50	53.86	.76
Barley	Soule, A. M., and Vanatter, P. O	1901	1	36.30	28.70	.79
Barley	Zavitz, C. A	1907	6	53.80	50.40	.94
Rye	Nielson, P	1895	4	26.70	25.70	.96
Winter wheat	Kiesselbach, T. A., and Helm, C. A	1917	4	43.20	41.30	.96
Oats	Kiesselbach, T. A., and Ratcliff, J. A	1917	5	46.10	41.00	.89
Spring wheat	Kiesselbach, T. A., and Helm, C. A	1917	2	14.10	12.70	.90
		Average	....	39.66	34.86	.88

TABLE 42—*Relative yields from large and small seeds when planted in equal weights, at a rate normal for the large seeds*

Crop	Investigator	Date of publication	Duration of test	Yield per acre			Ratio, unselected to large	Ratio, small to large
				Unselected seed	Large seed	Small seed		
			Years	*Bushels*	*Bushels*	*Bushels*		
Winter wheat	Kiesselbach, T. A., and Helm, C. A.	1917	4	45.2	43.2	43.2	1.05	1.00
Oats	Kiesselbach, T. A., and Ratcliff, J. A.	1917	5	45.2	46.1	46.1	.98	1.00
Spring wheat	Kiesselbach, T. A., and Helm, C. A.	1917	2	15.2	14.1	13.9	1.01	.99
		Average		35.5	34.5	34.4	1.01	1.00

TABLE 43—*Relative yields from large and small or heavy and light seeds as separated by a fanning mill and planted in equal volumes*

Crop	Investigator	Date of publication	Duration of test	Yield per acre: Large or heavy seed	Yield per acre: Small or light seed	Ratio, small to large
			Years	*Bushels*	*Bushels*	
Winter wheat	Georgeson, C. C	1896	4	29.15	27.60	.95
Winter wheat	Grenfall, C. N	1901	1	9.70	7.50	.77
Winter wheat	Kiesselbach, T. A., and Helm, C. A	1917	12	33.90	33.00	.97
Winter wheat	Hickman, J. F	1897	4	14.00	13.74	.98
Winter wheat	Hickman, J. F	1901	9	17.06	16.21	.95
Winter wheat	Lyon, T. L	1905	4	24.50	23.70	.97
Winter wheat	Latta, W. C	1891	3	30.54	27.94	.91
Winter wheat	Montgomery, E. G	1908	8	30.20	29.00	.96
Winter wheat	Sanborn, J. W	1893	4	17.66	14.98	.85
Winter wheat	Williams, C. G	1905	2	22.64	22.17	.98
Winter wheat	Williams, C. G., and Welton, F. A	1911	7	31.26	31.32	1.00
Oats[1]	Burnett, L. C	1912	3	49.00	48.75	.99
Oats	Boss, A	1893	1	64.09	54.59	.85
Oats	Georgeson, C. C	1897	8	30.90	27.50	.89
Oats (Kherson)	Kiesselbach, T. A., and Ratcliff, J. A	1917	12	55.45	54.71	.99
Oats (American Banner)	Kiesselbach, T. A., and Ratcliff, J. A	1917	4	39.70	43.37	1.09
Oats	Montgomery, E. G	1908	3	65.80	64.30	.98
Oats	Williams, C. G	1903	7	46.31	42.63	.92
Oats[2]	Williams, C. G., and Welton, F. A	1913	4	58.98	56.66	.96
Rye	Nielson, P	1895	7	38.2	38.80	1.02
Barley	Voelcker, J. A	1906	1	32.10	36.40	1.13
		Average		35.30	34.04	.96

[1]Average of two grades for each yield.
[2]Average data for equal volumes and equal numbers.

TABLE 44—*Relative yields from unselected and large and small or heavy and light seeds as separated by a fanning mill and planted in equal volumes*

Crop	Investigator	Date of publication	Duration of test	Yield per acre			Ratio, unselected to large	Ratio, small to large
				Unselected seed	Large or heavy seed	Small or light seed		
			Years	*Bushels*	*Bushels*	*Bushels*		
Winter wheat	Georgeson, C. C.	1896	4	28.97	29.15	27.60	.99	.95
Winter wheat	Kiesselbach, T. A., and Helm, C. A.	1917	12	33.50	33.90	33.00	.99	.97
Winter wheat	Hickman, J. F.	1897	4	13.37	14.00	13.74	.96	.98
Winter wheat	Hickman, J. F.	1901	9	16.33	17.06	16.21	.96	.95
Winter wheat	Montgomery, E. G.	1908	8	30.00	30.20	29.00	.99	.96
Winter wheat	Sanborn, J. W.	1893	4	16.42	17.66	14.98	.93	.85
Oats	Georgeson, C. C.	1897	8	29.89	30.90	27.50	.97	.89
Oats (Kherson)	Kiesselbach, T. A., and Ratcliff, J. A.	1917	12	54.62	55.45	54.71	.98	.99
Oats (American Banner)	Kiesselbach, T. A., and Ratcliff, J. A.	1917	4	41.77	39.70	43.37	1.05	1.09
Oats	Montgomery, E. G.	1908	3	65.40	65.80	64.30	.99	.98
Oats	Williams, C. G.	1903	7	44.77	46.31	42.63	.97	.92
Oats[1]	Williams, C. G., and Welton, F. A.	1913	4	58.23	58.98	56.66	.98	.96
		Average	....	36.10	36.60	35.30	.98	.96

[1]Average for equal volumes and equal numbers.

TABLE 45—*Relative yields of large and small seed planted alone and in competition*

Crop	Investigator	Date of publication	Duration of test	Relative yields			
				Alone		Competition	
				Large	Small	Large	Small
			Y'rs	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Winter wheat	Kiesselbach, T. A. and Helm, C. A...	1917	2	100	89	100	76
Oats........	Montgomery, E. G	1912	1	100	93	100	80
		Av..	....	100	91	100	78

In general the results indicate:

(a) When space-planted to permit maximum development, a higher individual plant yield is obtained from large than from small seeds. As an average for all investigations, this difference amounts to 17 per cent. This is not to be regarded as an inheritable quality, but rather as an immediate advantage due to a more vigorous initial growth resulting from a greater reserve food supply in the seed.

(b) When planted in equal numbers at a rate optimum for large seed, a lower yield is obtained from the small than from the large seed. As an average for all investigations, this difference amounts to 12 per cent. This comparison resolves itself in a measure into a rate-of-planting test. The optimum number of plants, per unit area, from large seeds is too thin for maximum results from small seeds.

(c) When planted in equal weights, at a rate optimum for the large seed, all three grades—large, small, and unselected—yield equally. As an average for all investigations, large and small seed yielded alike, and the unselected seed yielded 1 per cent more than the large. This also seems to be a matter of rate planting. The shortage in yield of plants from small seeds is overcome by planting a greater number of seeds.

(d) When light and heavy seeds (or large and small) obtained from a fanning mill are planted in equal volumes as with a drill set at a uniform rate, slightly smaller yields are apt to result from the small seed. As an average for all investigations, this difference amounts to 4 per cent. The difference in favor of large or heavy seed as compared with the original unselected seed is very slight, and probably so small as to have little practical significance. As an average for all tests it amounts to 2 per cent

increased yield for the large or heavy seed. Two per cent could easily be interpreted as experimental error if the tests were not so consistent in their indications. It is not likely that the yields are absolutely accurate. The conclusion would seem justified that the practical use of the fanning mill in seed preparation is to remove weed seeds and trash, when present. If the seed is well cleaned at the threshing machine, little further is to be gained by fanning mill grading.

(e) When large and small seeds are alternated in the row at the normal planting rate and grown thus in competition, plants from the small seeds are reduced in relative yield as a result of the competition. As an average for the two tests bearing on this point, this competition in favor of the large seed amounts to 13 per cent. This suggests a natural elimination (within a mass variety) of poorly adapted types, which produce unduly small or light-weight seed.

BIBLIOGRAPHY

Cited in this bulletin on page—

BOLLEY, H. L.
1901. Work with Wheat in 1900. (North Dakota Experiment Station, Eleventh Annual Report, pp. 28-32) 60, 64

BOSS, ANDREW
1893. Heavy vs. Light Oats for Seed. (Minnesota Agricultural Experiment Station Bul. 31, Annual Report, p. 213) 63, 67

BURNETT, L. C.
1912. Some Data for Oat Growers. (Iowa Agricultural Experiment Station Bul. 128, pp. 105-110) 63, 67

COBB, N. A.
1903. Seed Wheat. (Agricultural Gazette of N. S. Wales, Vol. XIV, Part 1, p. 145) 60, 64

CUMMINGS, M. B.
1914. Large Seed a Factor in Plant Production. (Vermont Agricultural Experiment Station Bul. 177, pp. 90-173).

DEGRULLY, L.
1898. On the Selection of Seed by Their Specific Weight. (Prog. Agr. et Vit. 30, No. 42, pp. 453-455).

DUGGAR, B. M.
1911. Plant Physiology. (New York, p. 287) 9

GEORGESON, C. C., H. M. COTTRELL, and WILLIAM SHELTON
1890. Experiments with Oats. Light and Heavy Seeds. (Kansas Agricultural Experiment Station Bul. No. 13, pp. 59-60).

GEORGESON, C. C.
1896. Experiments with Wheat. (Kansas Agricultural Experiment Station Bul. 59, p. 99) 62, 67, 68
1897. Experiments with Oats. (Kansas Agricultural Experiment Station Bul. 74, pp. 199-200) 63, 67, 68

GRANDEAU, L.
1898. Influence of the Weight of Seed on the Yield of Cereals. (Jour. Soc. Agr. Brabant et Hainaut, 1898, No. 47).

GRENFALL, C. N.
1901. Some Experiments with Wheat. (Agricultural Gazette of N. S. Wales, 12, p. 1053 .... 62, 67

HICKMAN, J. F.
1897. Field Experiments with Wheat. (Ohio Agricultural Experiment Station Bul. 82, p. 231) 62, 67, 68
1901. Field Experiments with Wheat. (Ohio Agricultural Experiment Station Bul. 129, p. 25) 62, 67, 68

HICKS, G. H. and DABNEY, J. C.
1896. The Superior Value of Large, Heavy Seed. (U. S. Department of Agriculture Yearbook, pp. 305-322).

JODIN, V.
1897. Recherches sur la Germination. (Annales Agronomiques, 33, pp. 433-471).

KIESSELBACH, T. A. and HELM, C. A.
1917. Relation of Size of Seed and Sprout Value to the Yield of Small Grain Crops. (Nebraska Agricultural Experiment Station Research Bul. 11).

Cited in this bulletin on page—

KIESSELBACH, T. A. and RATCLIFF, J. A.
1917. Oats Investigations. (Nebraska Agricultural Experiment Station Bul. 160) 63, 65, 67, 68

LATTA, W. C.
1891. Experiments with Wheat. (Indiana Agricultural Experiment Station Bul. 36, p. 115) 62, 67

LEIGHTY, C. E.
1912. Correlation of Characters in Oats, with Special Reference to Breeding. (American Breeders' Association Report 7, p. 50).

LILL, J. C.
1910. Relation of Size, Weight and Density of Kernel to Germination of Wheat. (Kansas Agricultural Experiment Station Circular 11, p. 3).

LOVE, H. H.
1912. A Study of the Large and Small Grain Question. (American Breeders' Association Report 7, p. 109).

LYON, T. L.
1902. The Adaptation and Improvement of Winter Wheat. (Nebraska Agricultural Experiment Station Bul. 72) 53
1905. Improving the Quality of Wheat. (U. S. Department of Agriculture, Bureau of Plant Industry Bul. 78, Part II, pp. 49-75) 53, 62, 67

MONTGOMERY, E. G.
1908. The Use of the Fanning Mill for Selecting Seed Wheat and Oats. (Nebraska Agricultural Experiment Station Bul. 104, p. 32) 53, 62, 63, 67, 68
1910. Methods for Testing the Seed Value of Light and Heavy Kernels of Cereals. (Journal of the American Society of Agronomy, Vol. II, pp. 59-70).
1912. Competition in Cereals. (Nebraska Agricultural Experiment Station Bul. 127, pp. 14-15) 26, 59, 65, 69

MYERS, C. H.
1912. Variation and Correlation in Wheat. (American Breeders' Association Report 7, p. 61).

NIELSON, P.
1895. Culture Experiments with Rye. (Tidsskr. Landbr. Planteavl. 1, pp. 1-130, Experiment Station Record Vol. VII, pp. 204-205) 59, 63, 65, 67

SANBORN, J. W.
1893. Seed Selection. (Utah Agricultural Experiment Station Fourth Annual Report, pp. 168-169) 62, 67, 68

SHAMEL, A. D.
1904. The Improvement of Tobacco by Breeding and Selection. (U. S. Department of Agriculture Yearbook, pp. 440-442).

SHAW, G. W.
1906. The Selection of Seed Wheat. (California Agricultural Experiment Station Bul. 181, p. 162).

SNYDER, H.
1905. Heavy and Light Weight Grains. (Minnesota Agricultural Experiment Station Bul. 90, pp. 214-218).

Cited in this bulletin on page—

SOULE, A. M. and VANATTER, P. O.
1903. Seed Selection. (Tennessee Agricultural Experiment Station Bul. 4, Vol. XVI, p. 77) 59, 65
1901. Winter Wheat. (Tennessee Agricultural Experiment Station Bul. 2, Vol. XIV, pp. 42-45) 59
1901. Winter Cereals and Legumes. (Tennessee Agricultural Experiment Station Bul. 3, Vol. XIV, p. 5) 65

VOELCKER, J. A.
1902. Head vs. Tail Corn for Seed Wheat. (Journal of the Royal Agricultural Society of England, Vol. 63, p. 353) 61, 64
1903. Head vs. Tail Corn for Seed Wheat. (Journal of the Royal Agricultural Society of England, Vol. 64, p. 354) 61, 64
1906. Field Experiments. (Journal of the Royal Agricultural Society of England, Vol. 67, pp. 282-310) 63, 67

WEBBER, H. J. and BAYKIN, E. B.
1907. The Advantage of Planting Heavy Cotton Seed. (U. S. Department of Agriculture Farmers' Bul. 285, pp. 5-16).

WILLIAMS, C. G.
1903. Ten Years' Experiments with Oats. (Ohio Agricultural Experiment Station Bul. 138, p. 48) 63, 67, 68
1905. Experiments with Winter Wheat. (Ohio Agricultural Experiment Station Bul. 165, pp. 56-59) 61, 62, 64, 67

WILLIAMS, C. G. and WELTON, F. A.
1911. Wheat Experiments. (Ohio Agricultural Experiment Station Bul. 231, p. 7) 62, 67
1913. Experiments with Oats. (Ohio Agricultural Experiment Station Bul. 257, pp. 66-67) 60, 63, 64, 67, 68

ZAVITZ, C. A.
1907. Seed Grain Selection. (Report of the Ontario Department of Agriculture, Vol. II, Part I, Department of Farmers' Institutes, p. 87) 59, 65
1908. Continuous Selection of Seed Oats. (Report of the Ontario Department of Agriculture, Vol. I, p. 181) 59, 65

[6-30-17—5M]

RESEARCH BULLETIN NO. 12

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

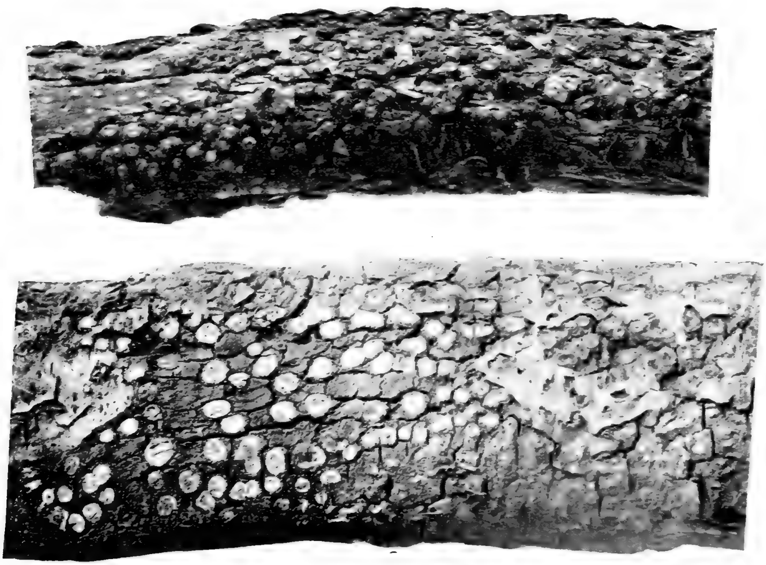
OF

NEBRASKA

STUDIES OF THE ETIOLOGY AND CONTROL OF BLISTER CANKER ON APPLE TREES

By J. RALPH COOPER

DISTRIBUTED DECEMBER 15, 1917



TYPICAL BLISTER CANKERS

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CONTENTS

STUDIES OF THE ETIOLOGY AND CONTROL OF BLISTER CANKER ON APPLE TREES

By J. Ralph Cooper

INTRODUCTION

The blister canker caused by *Nummularia discreta* Tul. is by far the most destructive disease of apple trees found in the United States. Serious damage due to this disease was first reported in Illinois in 1902. Since that time the disease has been reported to cause much damage in all apple-producing sections east of the Rocky Mountains. In Nebraska the disease is so prevalent that it is practically impossible to find an orchard free from it, and in many instances whole orchards have been destroyed thru its attacks.

Because of the rapid dissemination and the destructive nature of blister canker, the writer in the fall of 1912 began a series of experiments in an attempt to find some means of controlling it. It was soon found that little progress could be made in this direction without a thoro knowledge of the etiology of the disease. Accordingly this phase of the work was taken up in 1914 and both phases continued to date.

DISTRIBUTION

Our present knowledge of *Nummularia discreta* indicates that it causes a serious disease only of various species of Malus. However, it has been reported to cause cankers on Amelanchier, Gleditsia, Sorbus, Cercis, Ulmus, and Magnolia. The writer has succeeded in inoculating artificially both Pyrus communis and Amygdalus persica. Altho no characteristic cankers have appeared on either of these, microscopic examination has shown an abundance of invading hyphae thru the discolored area of the wood.

Since 1902, when it was reported as a destructive disease in orchards in Illinois, it has been reported in every apple-growing section east of the Rocky Mountains. It is especially

The writer is under great obligations to Dr. E. Mead Wilcox and Prof. R. F. Howard for valuable suggestions and encouragement, to Dr. Florence A. McCormick for advice and assistance in histology and microtechnique, to Grove M. Porter and Emmett B. Catterson for assistance in making inoculations, and to Miss Edna Beaty for assistance in assembling and checking data.

destructive in the region known as the Middle West,—Illinois, Indiana, Ohio, Iowa, Missouri, Kansas, and Nebraska.

Practically every orchard in the State has more or less infection. The extent of infection and amount of damage varies, as will be shown later, with the varieties of apples, soil conditions, amount of precipitation, and general weather conditions.

Owing to the fact that the fungus is a wound parasite and since the disease may exist in a tree for several seasons before becoming conspicuous or even noticeable, the distribution of infections appears very irregular and scattered in an orchard. Even when trees become infected at the same time, the disease shows externally on some trees long before it can be detected on others. After a time the disease becomes noticeable on all the infected trees, and finally they are killed. It is a common sight in Nebraska to see dead trees here and there thruout an orchard, and especially in neglected orchards to see whole blocks of dead trees, with here and there a tree which still has a few limbs bearing foliage and small apples.

HISTORY

The causal fungus was first described in America by Schweinitz[17] in 1834 under the name *Sphaeria discreta.* At that time it was considered to be a saprophyte and consequently of no economic importance.

In 1863 the Tulasne brothers[18] gave an excellent description of the fungus illustrated by numerous drawings. They renamed it *Nummularia discreta* by which name it is known at the present time. That they found it to be a parasite is shown by their statement: "It grows with us during the autumn and winter on *Sorbus hybrida* L. on the thick bark which has recently died." However, they attached no importance to the fungus as the causal organism of the disease.

It remained for Hasselbring[11] to observe the destructiveness of the disease caused by this fungus. In 1902 he noted a cankerous disease very prevalent and doing a great deal of damage to orchards in Illinois, which he called Illinois canker. He found the disease was caused by the fungus *Nummularia discreta.* In his report he gave a very comprehensive account of the symptoms and general appearance of the disease, but aside from this added little to the knowledge already furnished by Tulasne.

[17]These references are to the bibliography, page 68.

In 1912 Gloyer[10] of Ohio published a circular on "Blister Canker" caused by *Nummularia discreta,* but added little of any importance to the facts already published.

The disease was first noted in Nebraska about 1903 but it received no attention and no report was made except to mention its presence in the State.

SYMPTOMS AND GENERAL APPEARANCE

It is impossible to describe the symptoms of blister canker so that the casual observer will be able to identify the disease in all cases. Under certain conditions the symptoms are very marked and characteristic, as indicated by Hasselbring[11], but under other conditions these characteristic symptoms are wanting. The injury often resembles very closely that caused by other agencies such as winter injury, sun scald, blight, collar rot, and the so-called arsenical poisoning. The writer is of the opinion that a large share of the damage attributed to other causes is in reality caused by *Nummularia discreta.* The symptoms vary with the variety of trees, point of inoculation, soil conditions, amount of precipitation, general weather conditions, and treatment of the orchard. On the more resistant varieties sharply defined cankers usually appear. In the earliest stage the bark takes on a darker brown color and soon becomes slightly shrunken, and depressed below the adjoining healthy bark. The canker usually does not begin at one small point and spread, but a considerable area of affected bark will appear rather suddenly and continue to grow in size, spreading most rapidly in the direction of the long axis of the limb. The initial spots vary in size, being anywhere from two to eighteen or more inches long and one-half to six inches wide. The inner bark in these spots and at the edges of old cankers has a mottled appearance due to intermingling of dead areas within the living tissues. The size of the original cankered spot and the mottled appearance of recently affected areas are due to the fact that the fungus invades the older xylem tissues of the tree first and then works gradually toward the surface, killing the tissues as it advances. The advance is naturally more rapid in certain portions of the affected area than in others. Consequently the bark is not attacked evenly, but in spots wherever the fungus has approached near enough to the surface to kill the cambium. The bark is never attacked until the underlying tissues are killed.

During the months of July, August, and September small round blister-like protuberances one-eighth to one-quarter

inch in diameter appear all over the affected surface, or in the case of large spots where the center has become hard and dry, only along the margin of the cankered area. These "blisters" are caused by the formation of stromata (masses of spore-bearing mycelium) beneath the surface of the bark. Spores (conidia) are produced during the latter part of the same season or early the next spring. The blisters are ruptured by the pressure from beneath, disclosing a pale grayish-tan colored mass of mycelium and spores.

The cankered area increases in size each season as long as the branch remains alive. The bark of the older portions becomes blackened and rough. The stromata become flat or concave on the surface. Continued growth at the edges causes them to assume very irregular outlines. Often several blend into one, covering an area of nearly an inch in diameter. The surfaces of the stromata often appear light gray in color during the early spring, due to the growth of mycelium and the production of spores (conidia). Later, especially after the bark has been thoroly wetted by rains, the surface of these same stromata may appear coal-black due to the presence of ascospores which have been formed on the interior and forced to the surface.

With age the cankered bark begins to crack in all directions and fall off, leaving irregular patches of dead wood exposed. The stromata, however, usually remain firmly attached to the wood by means of a ring of fungous tissue for a considerable period of time after the bark has fallen away. If these stromata are removed, irregular dark brown to black rings, showing the points of attachment, may be seen in the lighter colored wood.

The point of inoculation often greatly influences the symptoms of the disease. Where entrance is gained thru a large wound, cankers are usually formed first at the point of initial infection, but if thru a small wound or thru a frost crack in the trunk or any of the main branches, the wound usually closes and the first cankers may appear in some of the branches which have been weakened or wounded. In cases of this kind one or more whole limbs often die in one season and usually few, if any, stromata are formed on their dead surfaces. When stromata are found in such cases, they are at the base of the limb where the fungus can still draw on the living tree for food. Where the inoculation takes place near the extremity of a branch, the branch is as a rule gradually cankered its entire length and stromata usually dot the whole surface. In all cases stromata are formed more abundantly

where the cankers are protected from direct sunlight, but on the other hand light does not affect the location of cankers.

Inoculation very often occurs thru wounds at the base of the tree made by rodents or by machinery in cultivation. In such instances, where the wounds are too large to heal over at once, the cankered margins advance and the bark falls away, but stromata are rarely found except on young trees or where new branches arise near enough to the wounds to be affected.

Inoculation often occurs in roots near the surface of the ground thru wounds made in cultivation or otherwise. In such cases that portion of the root is usually killed and the disease first becomes manifest as a canker at the crown. Sometimes the whole root system is affected but the fungus grows from one root to another with much more difficulty than from one branch to another, so that, as a rule, even tho a part of the roots may be killed, the others will remain intact until after the whole tree has become infected.

On the more susceptible varieties the symptoms are somewhat different. Whole trees often appear to be killed in a single season and no fruiting bodies appear, or one main limb after another may succumb in a single season and produce stromata only at the base near portions of the tree which are still alive. In many instances stromata form on the limbs during the same season that the disease first appears in the form of visible canker, but many of them never produce spores. Many more never rupture the epidermis, and practically no ascospores are ever produced. The perfect stage of the fungus is rarely found abundantly on the most susceptible varieties except when the cankers occur on the trunk or very large limbs, and even then it is often wanting owing to thick, corky bark which hinders the formation of stromata. However, enough immature or sterile stromata may usually be found upon a minute examination of the tree to identify the disease.

The disease makes rapid progress in trees suffering from drouth. The effects of drouth will be discussed later. Here again the symptoms are often somewhat modified. Whole limbs or even whole trees often die in a single season, or the bark may die only in long strips, sometimes reaching from the tip to the base of the limb, while the remaining bark will remain alive sometimes for several months. Infected trees suffering from drouth often put forth foliage and set an abundant crop of fruit only to have both leaves and fruit wither and die. In case the limb or tree does not die outright the leaves turn yellow and the fruit, while it reaches a certain

state of maturity, seldom attains sufficient size to be worth harvesting. Stromata are rarely formed in large numbers. These symptoms, while most commonly found associated with drouth conditions, are by no means confined to trees under such conditions. Badly affected roots or trunk may induce the same symptoms.

DESCRIPTION OF THE FUNGUS

CONIDIAL STAGE

As before stated, blisters appear during the late summer months upon the surface of the newly cankered areas. These blisters are caused by the formation of circular interwoven masses of mycelium just beneath the surface of the bark. Conidiophores arise from the surface of these stromata. They are short and usually more or less branched. Several conidia may be borne on the tip of each branch. Both conidiophores and conidia are nearly hyaline. Gloyer[10] not inaptly uses the term "honey colored" in describing them. The conidia are oval, rather sharply pointed at the attached end, and measure about 5 by 8 microns, altho they are often smaller. The spores are set free by the layer of bark which covers the stromata being ruptured by the pressure of the conidiophores and spores beneath.

Conidia may be produced during the latter part of the season on one-year-old cankers. The same stromata may produce conidia the next spring and for several seasons thereafter. These subsequent crops of spores occur, however, only on cankers protected from direct sunlight. In many instances spores are not produced until the spring following the appearance of the canker. As before stated the stromata in many instances never produce spores at all, due to the death of the limb or tree cutting off the food and water supply of the fungus. During favorable seasons conidia are produced thruout the growing season but as a rule under Nebraska conditions they occur most abundantly in the early spring during the months of April, May, and June, and to a less extent in September and October.

Hasselbring[11] stated that he was unable to germinate the conidia, but Gloyer[10] found them to be quite viable and that they germinated readily in distilled and well water, prune decoction, and a 4 per cent sugar solution even after having been kept in the laboratory for three months.

The writer found no difficulty in germinating conidia, when taken as soon as they matured, in water, and synthetic

liquid and solid media, but found their viability to decrease rapidly with age. In tests made soon after maturity of the spores an average of 82.2 per cent germination was secured, using semi-solid and liquid synthetic media, and water cultures which contained one per cent each of cane sugar and peptone. There was little difference in the amount of germination in any of these media. Spores which were placed in a moist chamber for a few hours and then desiccated did not germinate at all. Spores which had been kept in the laboratory for six weeks gave a germination test of only 8.5 per cent. No satisfactory results were obtained from the use of solid media.

Upon germination the endospore gradually draws away from the exospore except near the points where the germ tubes emerge. Later the exospore is entirely broken up.

ASCOGENOUS STAGE

The perfect or perithecial stage of the fungus appears one or more years after the conidial stage. Under favorable conditions it appears the following season tho in many cases it does not appear at all. The perfect stage is rarely found except in cankers on the trunk and large branches. During the early spring and summer perithecia are formed in the stromata which have previously borne conidia on their surfaces. These perithecia are arranged more or less in layers beneath the surface of the stroma, and are 0.2 to 0.4 mm. wide by 0.3 to 1.8 mm. long. The older and larger perithecia lie near the center of the stroma and are connected with the surface by means of long narrow necks. New perithecia are formed both above and below the first layer and around the edges of the stroma gradually increasing its size. Two or more stromata may fuse at the edges forming one very large irregular stroma. The asci which are about 12 to 15 by 160 to 180 microns arise from all parts of the interior of the perithecia with their free ends extending diagonally toward the center and the neck. Asci of all stages of development may be found in the same perithecium. Interspersed among the asci are numerous long sterile mycelial threads. The asci contain eight oblong brownish-black spores each. These spores measure about 10 to 12 by 13 to 16 microns when dry, but upon absorbing moisture become almost spherical.

During wet weather the stromata absorb water readily and the spores are expelled in great quantities. Some remain clinging to the surface but many are thrown entirely free. Glass slides smeared with vaseline and suspended 1¾ inches

above a group of stromata placed on moist blotting paper in a covered vessel caught and held large numbers of spores.

Tulasne[18] stated that the spores are expelled in March or April. The writer has found spores being expelled during every part of the growing season depending upon weather conditions. Stromata kept in the laboratory for over three years expelled spores in large quantities within a few hours after being placed in contact with wet blotting paper. It is very common to find ascospores being expelled thru masses of conidiophores and conidia on the surface of the stroma.

The spores are hyaline until they attain full size when they assume a dark brown or black color with a lighter line extending along one side. Hasselbring[11] gave a very accurate description of their germination. He stated: "In germination the exospore cracks along the lines previously described. Two germ tubes originate from the endospore. These turn away from each other and remain at first closely appressed to the spore. Then they grow out in opposite directions."

Hasselbring found that oxygen is necessary to spore germination. The writer also found this to be true. Spores deeply embedded in poured plates did not germinate at all while the percentage of germination was high at or near the surface.

Ascospores retain their vitality for a long period of time. A large number of stromata were secured in the spring of 1914 and the spores tested for germination at intervals of three months. After three months the per cent of germination was 91.8. This was nearly 20 per cent higher than when the spores were first taken. This was probably due to the presence of a large number of immature spores when the stromata were gathered. After three years the per cent of germination was 31.9. It was found, however, that a great number of these spores were so reduced in vitality that the germ tubes grew to be only a few mm. in length and died. As was the case with conidia, few spores germinated when they were exposed in a moist atmosphere for several hours and then allowed to dry before the test was made.

MYCELIUM

Mycelial growth in artificial media is relatively slow from both conidia and ascospores. For this reason it was very difficult to secure pure cultures from conidia unless the spores were taken from those first matured on the stroma before the bark became ruptured. Later, spores of *Macrosporium* and *Fusarium* were often found intermingled with the conidia.

At first the hyphae from conidia are rather heavy and because of numerous large vacuoles appear abundantly septate. The hyhae produced after the cultures were a few days old could not be distinguished in any way from hyphae in ascospore cultures.

It was a simple matter to secure pure cultures from ascospores. The stromata were placed on moist blotting or filter paper in the bottom of deep petri dishes which had been sterilized. When the spores were expelled they adhered to the cover in large quantities. The spores were then transferred to poured plates. These cultures were usually free from contamination except for the presence of bacteria. Bacterial growth was prevented by acidifying the media with lactic acid.

Ordinarily the mycelium branches very little when young and the hyphae maintain a relatively direct course. Several mm. behind the growing tip the older part of the mycelium branches profusely. Many hyphae often arise at the same point on one or both sides of the main trunk and spread in a fan-shaped area over the media. These hyphae are usually much smaller than the parent stock. In the older cultures, compact masses of mycelium are formed at these points of division on which in many instances the writer has found conidiophores and conidia. Conidia were first noted in cultures which were sealed with paraffin and left for several months. An attempt made to germinate these spores met with failure. It was later found comparatively easy to induce cultures to produce conidia by checking growth suddenly or by allowing the culture to dry slightly. It was also found that the conidia would germinate readily.

Gloyer[10] indicates that the rate of growth of mycelium in apple wood was very rapid where the wood had lost a portion of its water content, but that no growth was made where the wood was sterilized with steam at 15 pounds pressure. He attributes this failure of growth to an excess of water caused by sterilizing with steam. In the dry wood he secured the phenomenal growth of 8 inches thru heartwood tissues in seven days, a feat which the author tried in vain to duplicate. Wood cylinders 1 inch in diameter were sterilized in mercuric chloride for 30 minutes and then washed in distilled water. The ends were next trimmed away with a sterilized knife to remove any mercuric chloride which remained, dipped in alcohol and the alcohol burned away. Others were sterilized by steam under 15 pounds pressure. Five sections sterilized each way were inoculated at one end and placed in cotton-plugged cylinders which permitted rapid evaporation of water.

TABLE 1—*The relation of age of tissues to susceptibility, and the comparative effectiveness of different inocula when introduced into various tissues of the tree*

HOW INTRODUCED	Region of Inoculation	INOCULUM	Number of Inoculations	Number Effective	Per cent Effective
On surface*	Bark	Ascospores	15	0	0.00
On bruised surface*	Bark	Ascospores	15	0	0.00
On shaved surface*	Bark	Ascospores	15	0	0.00
Bark lifted as in budding*	Current cambium	Ascospores	30	0	0.00
Incision by knife	Current xylem	Ascospores	30	8	26.67
Bark lifted as in budding	Cambium of limbs, 1 to 10 years old	Ascospores	101	49	48.51
Incision by chisel	1-year-old xylem	Ascospores	65	36	55.38
Incision by chisel	2-year-old xylem	Ascospores	52	46	88.46
Incision by chisel	3-year-old xylem	Ascospores	31	29	93.55
Incision by chisel	4-year-old xylem	Ascospores	36	36	100.00
Incision by chisel	5-year-old xylem	Ascospores	28	28	100.00
Surface of wound covered	Stubs ½ to 2″ in diameter	Ascospores	58	58	100.00
Surface of wound covered	Pruning wounds ½ to 2″ in diameter	Ascospores	52	51	98.08
Total			453	341	75.28

*Not included in total.

Five others were inoculated and placed in cylinders with ground glass stoppers which prevented evaporation. One section of each was examined each week. The first examination showed little growth in either case. The second week the sections from the cotton-plugged cylinder showed the most vigorous growth. The third week the hyphae had advanced in one of the sections sterilized with mercuric chloride in the cotton-stoppered cylinder 1¾ inches and in the one sterilized by steam 2¼ inches. In the sections where no evaporation was permitted the one sterilized with steam showed an advance of 1¼ inches in three weeks and the one sterilized with mercuric chloride 1 inch. After this time practically no growth was made in sections sterilized with mercuric chloride and allowed to dry. A growth of 3¼ inches was found the fifth week in the steamed section which was allowed to dry. Of the sections not allowed to dry out the one steamed, examined the fifth week, showed a growth of 2¾ inches while the one sterilized with mercuric chloride showed only 1½ inches. In the sections sterilized with mercuric chloride only the heartwood was invaded, but in those sterilized with steam even the bark was invaded. In all cases, but more noticeably where the wood was steamed, a dark brown slimy liquid exuded from the wood. This remained in the bottom of the tightly closed cylinders but soon dried up in those plugged with cotton.

Sections of branches were then dried by heat until 10 and 20 per cent of water respectively had been lost, and enclosed in cylinders as above. Growth was noted in only one case where the cylinders were plugged with cotton and only slight growth was secured where the cylinders were tightly closed.

Twelve branches one-half inch in diameter and bearing leaves were inoculated in one-year-old wood and placed with the cut ends in water. At the end of the sixth day the mycelium had grown above the inoculation an average of 4¼ inches. Branches which were inoculated and not placed in water showed practically no growth.

EXPERIMENTAL INFECTION

In 1914 a series of inoculations were planned in order to secure definite data on the manner in which the disease is most readily disseminated, how infection occurs, the rate of progress of the disease after infection occurs, varietal resistance and control measures. Actual work in the field was begun in May of 1915, altho inoculations had been made on trees in the

TABLE 2—*The relation of age of tissues to susceptibility, and the comparative effectiveness of different inocula when introduced into various tissues of the tree*

HOW INTRODUCED	Region of Inoculation	INOCULUM	Number of Inoculations	Number Effective	Per cent Effective
On surface*	Bark	Conidia	15	0	0.00
On bruised surface*	Bark	Conidia	15	0	0.00
On shaved surface*	Bark	Conidia	15	0	0.00
Bark lifted as in budding*	Current cambium	Conidia	30	0	0.00
Incision by knife	Current xylem	Conidia	30	1	3.33
Bark lifted as in budding	Cambium of limbs, 1 to 10 years old	Conidia	58	11	18.97
Incision by chisel	1-year-old xylem	Conidia	36	6	16.66
Incision by chisel	2-year-old xylem	Conidia	25	6	24.00
Incision by chisel	3-year-old xylem	Conidia	20	11	55.00
Incision by chisel	4-year-old xylem	Conidia	22	7	31.82
Incision by chisel	5-year-old xylem	Conidia	19	11	57.89
Surface of wound covered	Stubs ½ to 2" in diameter	Conidia	16	9	56.25
Surface of wound covered	Pruning wounds ½ to 2" in diameter	Conidia	21	14	66.67
Total			247	76	30.77

*Not included in total.

greenhouse before that. Over 2,000 field inoculations were made in trees of several varieties, ranging from 1 to 16 years old. Inoculations were made in every manner in which it was thought possible that infections could occur under field conditions. Ascospores, conidia, infected wood tissues, and pure cultures of the fungus were used as inocula.

In making the inoculations with pure culture and infected wood the surface to be inoculated was first washed with 95 per cent alcohol. The wound was then made with a sterilized knife, chisel or auger as the case might be. The inoculum was placed in position and the wound covered with a sterile cotton patch. This was in turn covered with a square of cloth coated with paraffin and the whole then wrapped with several layers of cloth saturated with grafting wax. The inoculations with other inocula were covered in the same way but the surface to be inoculated and the tools were not sterilized except in a portion of the operations. Care was exercised to use trees free from previous infection. To determine whether or not a tree was infected one or more large branches were sawed off close to the trunk, or borings were made with an auger, and trees which showed discolored wood were rejected.

ASCOSPORE INOCULATIONS

The spores were secured by cutting away the disc from a stroma and exposing the perithecia, then drawing out the spores by means of a pipette partly filled with water, or by causing the spores to be expelled and collecting them from the petri dish covers as has already been explained. The spores were placed in water in a bottle and inserted in the incisions by means of a bulb pipette.

Inoculations were made by spraying spores upon the uninjured surface of the bark of limbs and current growth,* and in like places after the bark had been bruised but not broken open. Others were made where the surface had been cut away but the cambium left uninjured. Inoculations were also made on current growth in the region of the cambium, by lifting the bark with a knife and inserting the spores, and in the xylem by making a slanting cut or by removing a portion of the wood. The same method of procedure was followed in making inoculations on older limbs except that a greater amount of wood was removed. The cuts were made to extend thru a definite number of annual rings from one to five below the

*By current growth is meant growth which occurred during the season in which the inoculations were made. Wood which matured the previous year is called one-year-old wood.

TABLE 3—*The relation of age of tissues to susceptibility, and the comparative effectiveness of different inocula when introduced into various tissues of the tree*

HOW INTRODUCED	Region of Inoculation	INOCULUM	Number of Inoculations	Number Effective	Per cent Effective
On surface*	Bark	Infected wood			
On bruised surface*	Bark	Infected wood			
On shaved surface*	Bark	Infected wood			
Bark lifted as in budding*	Current cambium	Infected wood	30	0	0.00
Incision by knife	Current xylem	Infected wood	30	0	0.00
Bark lifted as in budding	Cambium of limbs, 1 to 10 years old	Infected wood	62	8	12.90
Incision by chisel	1-year-old xylem	Infected wood	27	5	18.52
Incision by chisel	2-year-old xylem	Infected wood	26	5	19.23
Incision by chisel	3-year-old xylem	Infected wood	30	12	40.00
Incision by chisel	4-year-old xylem	Infected wood	28	8	28.57
Incision by chisel	5-year-old-xylem	Infected wood	25	20	80.00
Surface of wound covered	Stubs ½ to 2″ in diameter	Infected wood	20	14	70.00
Surface of wound covered	Pruning wounds ½ to 2″ in diameter	Infected wood	31	19	61.29
Total			279	91	32.62

*Not included in total.

surface in order to note the region in which the most active growth occurred. Branches were cut off leaving stubs 10 to 12 inches long and the cut surface evenly inoculated all over. Branches were also removed according to the most approved methods of pruning and the whole cut surface inoculated.

As indicated in table 1 no infection occurred from sprayed inoculations even when the bark was bruised or shaved. Neither did any infection result from inoculations in the region of the cambium on current wood. Twenty-six per cent of the inoculations made in the xylem of current growth were effective. It was noted, however, that infection occurred only in twigs where the deepest cuts had been made. It is evident that the wound reduced the resistance of the branch, since it was noted that this also occurred to some extent on larger limbs. Infection took place more readily where the wounded surface was comparatively large.

As shown in the same table the percentage of infections increased with the age of the tissue inoculated from the cambium to four-year-old xylem but there was little difference in susceptibility of four and five-year-old xylem. In fact the stub and pruning wound inoculations showed that from the age of four years on, there was little difference in the susceptibility of the wood to infection since infection usually started on stubs and pruning wounds quite evenly on all of the wood four years old and over, while on the younger wood there was a gradual reduction in the number of infections in each successive ring of newer tissue. No infection occurred in the cambium or outside of it except in very thick bark. In a few cases slight indications of infection were found toward the outer portion of the bark where inoculations were made in the trunk and large limbs, but in all cases the progress of the mycelium was so slow that injury from such infections is negligible. In no case was the cambium found to be injured.

A number of different varieties were used in the series represented in tables 1, 2, 3, and 4, but the same proportions of inoculations with the four inocula and the different tissues inoculated were maintained in all cases.

CONIDIA INOCULATIONS

A series of inoculations were made with conidia duplicating every feature of the series made with ascospores. Conidia recently matured were secured from stromata still protected wholly or in part by the covering of bark. None were taken from stromata bearing ascospores.

TABLE 4—*The relation of age of tissues to susceptibility, and the comparative effectiveness of different inocula when introduced into various tissues of the tree*

HOW INTRODUCED	Region of Inoculation	INOCULUM	Number of Inoculations	Number Effective	Per cent Effective
On surface*	Bark	Pure culture	15	0	0.00
On bruised surface*	Bark	Pure culture	15	0	0.00
On shaved surface*	Bark	Pure culture	15	0	0.00
Bark lifted as in budding*	Current cambium	Pure culture	30	0	0.00
Incision by knife	Current xylem	Pure culture	30	2	6.67
Bark lifted as in budding	Cambium of limbs, 1 to 10 years old	Pure culture	92	30	32.61
Incision by chisel	1-year-old xylem	Pure culture	64	20	31.25
Incision by chisel	2-year-old xylem	Pure culture	41	27	65.85
Incision by chisel	3-year-old xylem	Pure culture	34	26	76.47
Incision by chisel	4-year-old xylem	Pure culture	27	21	77.78
Incision by chisel	5-year-old xylem	Pure culture	38	30	78.95
Surface of wound covered	Stubs ½ to 2″ in diameter	Pure culture	47	42	89.36
Surface of wound covered	Pruning wounds ½ to 2″ in diameter	Pure culture	33	26	78.79
Total			406	224	55.17

*Not included in total.

The results tabulated in table 2 substantiate those in table 1 in regard to susceptibility of the various ages of tissue inoculated. The much lower percentage of infections indicates that the conidia are much less virile than the ascospores or that they are more easily inhibited. However, this was to be expected from the results of germination tests made in the laboratory.

INFECTED WOOD INOCULATIONS

The infected wood was secured by sawing out a section of a limb two to three feet above the external boundary of a well-defined canker. The bark was removed after which the wood was sterilized by being immersed in 95 per cent alcohol and flamed over a Bunsen burner. A sterilized coarse-toothed saw was used to reduce the wood to sawdust which was placed in wide-mouthed bottles and slightly moistened. The results given in table 3 show a slightly higher percentage of infection than was obtained by conidia. In the case of inoculations in the older tissues the percentage was decidedly higher. This might be due in part to the larger wounds which it was necessary to make in order to insert the sawdust, and in part to the fact that the fungus was already well established in the sawdust. Here again the older wood was found to be much more susceptible than the younger tissues. This infection by means of diseased wood clearly shows the futility of attempting to control canker by cutting away the canker itself, as long as any of the mycelium is left in the tree.

PURE CULTURE INOCULATIONS

The fungus was transferred from initial cultures to petri dishes containing a layer of media several mm. thick in order to prevent drying out quickly, and allowed to grow until the mycelium covered the surface of the medium in a heavy mat. Inoculations were then made by cutting out squares of the medium and inserting them in the incisions made in the tree. The percentage of effective inoculations was considerably higher than when either conidia or infected wood was used but not so high as when ascospores were used. As in the three previously mentioned series, the older tissues proved much more susceptible than those nearer the cambium. No infections occurred in current growth except where the xylem was deeply cut. In no case did the mycelium penetrate uninjured bark even tho the inoculum was placed in direct contact with the bark and covered.

TABLE 5—*Comparison of rate of growth of mycelium in tissues of different ages**

BEN DAVIS

CAMBIUM		One-year-old Xylem		Two-year-old Xylem		Three-year-old Xylem		Four-year-old Xylem	
Above Inocula-tion	Below Inocula-tion	Above Inocula-tion	Below Inocula-tion	Above Inocula-tion	Below Inocula-tion	Above Inocula-tion	Below Inocula-tion	Above Inocula-tion	Below Inocula-tion
Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
0.0	.5	2.0	7.0	10.0	13.0	12.5	36.5	20.0	34.0
1.0	1.0	4.0	5.0	6.0	6.5	31.0	14.0	46.0	48.0
3.5	1.0	1.5	5.0	2.5	2.0	17.5	16.5	29.5	31.5
1.5	1.0	6.0	2.5	3.0	5.5	13.0	15.0	51.0	50.5
1.5	2.0	1.0	5.0	16.5	14.5	11.5	18.0	21.5	24.0
.5	.5	2.5	4.5	5.0	8.0	20.0	19.5	36.0	21.5
4.0	4.5	2.0	7.0	10.0	14.5	29.0	31.0	39.5	36.0
3.0	4.0	1.5	1.5	11.5	11.5	3.0	4.5		
1.0	1.0	9.0	7.5	15.0	10.0	28.0	24.0		
1.0	1.5	2.5	2.5	14.5	19.0				
		2.5	6.0	3.0	12.5				
		13.0	15.0	14.0	13.0				
		13.5	12.0	3.5	3.5				
		6.5	10.5	11.0	16.0				
		10.0	10.0	14.0	18.5				
		4.5	10.5	15.0	17.0				
		2.0	8.0	16.5	15.0				
		14.5	0.0	16.5	18.0				
		12.0	8.5						
		13.0	9.0						
Av. 1.70	1.70	6.17	6.85	10.42	12.11	18.39	19.89	34.79	35.07

*Inoculations were made in the spring of 1915 and examined in November, 1916.

TABLE 5—*(Cont'd)—Comparison of rate of growth of mycelium in tissues of different ages**

JONATHAN

CAMBIUM		One-year-old Xylem		Two-year-old Xylem		Three-year-old Xylem		Four-year-old Xylem	
Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation
Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
1.5	1.5	4.0	8.0	6.0	2.5	11.0	8.5	36.5	41.0
1.0	1.0	3.0	8.0	3.5	4.0	16.0	18.0	25.5	27.5
.5	.5	4.5	3.0	3.0	4.5	8.5	10.5	22.0	17.0
1.0	1.0	2.0	3.5	20.5	40.0	11.0	11.5	28.5	27.5
.5	.5	3.0	4.0	8.0	6.0	14.5	12.0	12.0	14.0
2.5	1.0	9.0	7.5	9.5	14.5	6.5	11.0		
1.0	1.0	1.0	1.0	15.0	16.5	9.0	9.5		
.5	.5	1.0	2.5	3.5	4.0	7.5	11.5		
1.5	1.5	3.5	4.0	4.0	7.5				
1.0	.5	2.0	3.0	3.0	5.0				
2.5	2.5	2.5	2.0	3.5	9.5				
		3.5	3.0	2.0	3.0				
		2.0	2.5	4.5	5.5				
		3.5	3.5	3.0	4.5				
		2.5	2.0	2.5	1.0				
		1.5	2.5						
		2.5	2.0						
		14.5	15.0						
		3.0	3.5						
		2.0	2.0						
		1.5	1.5						
		0.0	4.0						
		2.0	3.0						
		13.5	11.0						
Av. 1.23	1.05	3.65	4.25	6.10	8.53	10.50	11.56	24.90	25.40

*Inoculations were made in the spring of 1915 and examined in November, 1916.

The foregoing data clearly indicate that the fungus is a wound parasite and that the older the tissues exposed by wounding the greater is the danger of infection. All wounds are liable to infection, and since wood older than five years is the most susceptible it is especially dangerous to leave large pruning wounds unprotected.

It is evident that the disease may be disseminated by means of ascospores and conidia, and by infected particles of wood which may cling to the pruning tools. On account of their greater virility ascospores are perhaps the greatest menace, altho even with the short period of time during which they are viable, conidia offer a great source of infection due to the fact that they are formed in such large quantities over a long period of the growing season.

ROOT INOCULATIONS

Inoculations were made with ascospores in roots of Jonathan and Ben Davis trees, with the same general results. It was impossible to infect roots near their rapidly growing tips, and one-year-old wood was found to be very resistant. Shallow roots were always more susceptible than those 12 or more inches below the surface of the soil. However, this was manifest by the slow progress of mycelium in deep roots as compared with the rate of growth in roots near the surface more than by the number of effective inoculations. The percentage of effective inoculations was much lower in all roots than in the portion of the tree above ground. In the roots 39.4 per cent were effective as compared with 75.27 per cent in the trunk and branches.

DETERMINATION AND IDENTIFICATION OF INFECTION

In order to determine the number of inoculations which produced infection it was necessary to section and stain the wood and examine it under the microscope. At first the fungus-bearing tissues were killed by the use of formalin and alcohol, corrosive sublimate, and picric acid and corrosive sublimate. The formalin alcohol solution proved the most satisfactory since no washing or clearing was necessary before sectioning. An attempt was made to conserve time and labor still more, since there were so many inoculations to be examined, by sectioning the wood without killing. This proved so satisfactory that with the exception of a few which were run thru the celloidin process all the remaining specimens were treated in this way. The sections were cut with a sliding microtome using a very heavy blade.

The greatest difficulty lay in obtaining a desirable stain. Several were tried with unsatisfactory results. The Pianese stain used by Vaughan[21] was promising but required a long time to stain the hyphae and when this was accomplished the staining of the cells was so dense that the hyphae were obscured. At the suggestion of Doctor McCormick the formula was changed as well as the subsequent treatment of the sections with very gratifying results. The modified formula was:

Malachite green	0.50	gm.
Acid fuchsin	0.50	gm.
Martius gelb	0.02	gm.
Water (distilled)	150.00	cc.
Alcohol (95 per cent)	50.00	cc.

The sections were cleared in carbolturpentine, washed in 95 per cent and absolute alcohol and stored in xylol. Mountings were in balsam. By this method the cells were stained green and the hyphae a deep pink. Staining required only two to five minutes.

By comparing the discoloration of inoculations where microscopic examination revealed the hyphae invading the tissues with that made by incisions where no inoculum was inserted, it was found extremely easy in the majority of cases to recognize infections. Therefore, after more than 200 inoculations had been examined to the extreme limits of the invaded tissues, the presence of the characteristic discoloration was taken as an indication of the presence of infection, except in doubtful cases when the microscope was employed.

No inoculations were made from these artificial infections.* The fact that characteristic stromata and conidia were produced from infections caused by each of the inocula used was considered ample proof as to the identity of the infections. No ascospores have yet been produced on any of the cankers from artificial infection.

While examining inoculations for infection, it was observed that in a number of cases the infection extended to all parts of the tree. This aroused a suspicion that the tree might have been infected at some previous time in spite of the precautions taken to select sound trees, especially as several places were found where infection might have occurred, such as frost cracks in the trunk and old pruning wounds. This led to the examination of a large number of trees which showed no visible signs of canker. The results were discour-

*Since preparing this manuscript the author has isolated the causal fungus from some of these artificial infections and made new inoculations which have produced typical cankers.

TABLE 6—*Rate of growth of mycelium in inoculated stubs*†

BEN DAVIS

DIAMETER OF STUBS							
½ Inch		1 Inch		1½ Inches		2 Inches	
Distance Below Inoculation		Distance Below Inoculation		Distance Below Inoculation		Distance Below Inoculation	
5 Inches	10 Inches	5 Inches	10 Inches	5 Inches	10 Inches	5 Inches	10 Inches
0*	1*	0*	2*	0*	1*	0*	3*
0*	0*	0*	0*	0*	0*	0*	2*
0*	1*	0	1	0*	2*	0*	2*
0*	0*	0*	1*	1	3	3	6
0*	2*	0*	0*	1*	2*		
1	4	0*	0*	0	3		
1	4	0*	0*	1*	1*		
0*	0*	0*	0*	1	2		
0*	2*	0	3	2	3		
0*	0*	0*	1*	0*	2*		
0*	0*	4	4	3	5		
1*	1*	1	2	4	5		
1	2	0*	0*	3	3		
1*	2*	1	3	2	3		
2	3	2	4	1*	2*		
1	2	1*	1*				
3	4	0*	1*				
0*	1*	3	5				
		0*	3*				
Av. .51	1.51	.63	1.63	1.26	2.46	.75	3.25

*Cankers with characteristic stromata appeared on these inoculations.

†Figures represent annual rings of wood free from discoloration, counting from surface.

TABLE 6—*(Continued)*—*Rate of growth of mycelium in inoculated stubs*†

JONATHAN

DIAMETER OF STUBS							
½ Inch		1 Inch		1½ Inches		2 Inches	
Distance Below Inoculation		Distance Below Inoculation		Distance Below Inoculation		Distance Below Inoculation	
5 Inches	10 Inches	5 Inches	10 Inches	5 Inches	10 Inches	5 Inches	10 Inches
2	3	1	4	3	5	0*	1*
0*	1*	1	2	2	5	3	4
1	3	2	3	2	5	4	7
0*	0*	0*	0*	3	5		
0*	0*	1	4	3	8		
0*	1*	5	9	7	10		
0*	1*	0*	0*	6	9		
2	4	2	5	0*	2*		
1	3	2	3	5	5		
2	3	2	3	6	6		
2	2	2	4				
3	7	5	7				
3	5	0*	1*				
2	4	5	8				
4	6	6	7				
Av. 1.46	2.86	2.26	4.00	3.70	6.00	2.33	4.00

*Cankers with characteristic stromata appeared on these inoculations.

†Figures represent annual rings of wood free from discoloration, counting from surface.

aging in that of 42 apparently sound trees examined, which were from 12 to 16 years old, only 3 were free from the fungus. In a number of cases infection was traced to cracks and other wounds in the trunk, several to pruning and other wounds in the limbs and a smaller number to injury to the roots near the surface of the ground.

This led to omitting from the data any infection which could not be followed from the inoculation to the end of infections except in a few cases specifically mentioned later, such as stub inoculations and inoculations in four trees which had been root pruned.

GROWTH OF MYCELIUM IN THE WOOD

INOCULATION IN TISSUES OF DIFFERENT AGES

The growth of the mycelium within the tree varies with the age and condition of the wood. In tissues which are still active the hyphae are confined largely to the tracheal vessels and the medullary ray cells, altho the adjacent sclerenchyma cells are slowly invaded as the tissue dies. The hyphae advance rapidly along the tracheae passing from one to the other and to adjacent cells thru the pits in the cell walls. This explains why recent infections appear as long brownish-black threads in the wood. The tracheae offer little resistance to progress of the fungus lengthwise of the branch, but lateral progress thru the medullary ray cells and the adjacent sclerenchyma is very slow.

The most rapid progress occurs in that part of the annual growth made early in the spring when the tracheal vessels are relatively large and abundant. Here many of the parallel tracheae communicate thru pits so that the progress laterally is also relatively rapid. The annual ring of growth on either side is protected from invasion to some extent by the barrier of small, thick-walled, nonpitted wood cells which form late in the season's growth. Tracheae in this region are fewer and somewhat smaller. However, the regions of the different annual growths communicate by means of the medullary rays and thru these are finally invaded. As the fungus goes deeper into the branch each succeeding year's growth up to four-year-old wood is found more susceptible. However, from here on there is practically no difference in the susceptibility of the tissue of different ages altho there is the same relative rate of progress in the different cells. This difference in susceptibility of tissues of different ages which varies in different varieties and individual trees of the same variety is no doubt

due to the presence of protoplasm in the still active tissues. This is shown by the fact that in the laboratory the one-year-old xylem of wood cylinders in which the protoplasm had been killed was invaded as readily as the old heartwood, but was not invaded in cylinders where the protoplasm was not killed.

As shown by the data in table 5, while infection occurs in xylem of all ages the rate of growth is very slow in the outer annual rings of growth, as compared with the older tissues. Infections also took place from the inoculations in the region of the cambium, but examination showed that the infection was in the xylem lying just beneath. Where the strands were found just beneath the cambium an extra number of small wood cells were found between the infection and the cambium. In many cases where the infection was in small limbs this caused a distinct ridge in the bark which extended as far as the end of the diseased streak.

These inoculations were made in May, 1915, and examined in November, 1916. The time which had elapsed was equal to almost two growing seasons.

In determining the amount of growth made by the mycelium, microscopic examinations were made as in the case of identifying infections. In fact many of the inoculations served the same purpose. At first sections were made and examined every inch above and below the inoculation until no discolored strands showed in the tissues. It was soon found that the hyphae could be found easily until the region within two to three inches of the end of the brown strands was reached where they became very few and were found only in the tracheae. In the majority of cases, however, on close examination hyphae were found within a few mm. of the end of the discolored areas. Accordingly in measuring the distance covered by the hyphae the end of the discoloration was taken as the limit of infection. Radially hyphae were nearly always found to extend to within at least one or two cells of the margin of the discolored area except in the case of the medullary rays where the distance was sometimes greater.

In the long axis of the branches the active tissues are killed one to three or even more inches ahead of the invading hyphae. The whitish dry spots may often be seen in cross section with the naked eye. The killed area is readily determined by staining and by plasmolysis tests. In using the Pianese stain it was found that the dead cells stained much less readily than those which were still active. For this reason the cells of the infected sections were much lighter in color or were only

TABLE 7—*Rate of growth of mycelium in trees of different ages*

VARIETY	AGE OF TREES							
	1 Year		2 Years		3 Years		4 Years	
	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation	Above Inoculation	Below Inoculation
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Ben Davis	6.5	4.5	9.0	4.5	14.0	15.0	17.0	18.5
	7.0	8.0	8.5	9.0	9.0	15.5	14.5	17.5
	3.5	5.5	11.5	12.5				
Average	5.67	6.00	9.66	8.67	11.50	15.25	15.75	18.0
Winesap	4.0	4.0	4.0	5.0	6.5	7.5	8.5	10.0
	4.5	5.5	3.0	7.0	4.5	.0	7.5	8.5
	2.0	3.0	2.0	4.0				
Average	3.50	4.17	3.00	5.33	5.50	3.75	8.00	9.25
Delicious	4.0	8.0	2.0	2.0	14.0	7.0	19.0	14.5
	8.0	10.0	6.0	7.0	14.5	5.5	18.5	16.0
	4.0	8.5	4.5	5.0				
Average	5.33	8.83	4.17	4.67	14.25	6.25	18.75	15.25

TABLE 7—*(Continued)—Rate of growth of mycelium in trees of different ages*

VARIETY	AGE OF TREES							
	1 Year		2 Years		3 Years		4 Years	
	Above Inocula-lation	Below Inocula-lation	Above Inocula-lation	Below Inocula-lation	Above Inocula-lation	Below Inocula-lation	Above Inocula-lation	Below Inocula-lation
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
York	4.0	4.0	3.0	3.5	8.5	8.0	8.5	7.5
	5.0	7.5	3.0	3.0	4.5	7.0	8.0	8.5
	4.0	6.0	4.0	4.5				
Average	4.33	5.83	3.33	3.67	6.5	7.5	8.25	8.00
Jonathan	2.0	2.0	4.0	4.0	9.0	15.0	6.5	8.5
	2.0	10.5	8.5	9.0	4.0	6.5	8.5	9.5
	1.0	1.5	2.0	6.0				
Average	1.67	4.67	4.83	6.33	6.50	10.75	7.50	9.00
N. W. Greening	2.5	4.5	4.0	4.0	11.5	21.5	8.5	14.0
	2.5	4.5	3.0	3.0	7.0	8.0	7.5	16.5
	1.0	3.5	4.0	4.0				
Average	2.00	4.17	3.67	3.67	9.25	14.75	8.00	15.25

lightly stained while the adjoining cells always took on a deep stain. By employing this stain it was found that unstained or lightly stained spots appeared in sections made beyond the actual discoloration in the branches and that these spots corresponded in position with the area occupied by the fungus in infected sections.

The cells in such spots did not respond when treated successively with 20 per cent cane sugar and distilled water. However, the surrounding cells did not always respond satisfactorily but there was sufficient response to show the presence of living protoplasm in the majority of cases.

It was noted that in general the mycelium grows more rapidly in a downward than in an upward direction. This is especially true in inoculations on the smaller limbs, and on the larger limbs where a great deal of growth has been made. In the larger limbs where the hyphae have proceeded only a short distance the average growth is as great in one direction as another. The difference in growth in smaller limbs is perhaps due to the fact that the ascending hyphae are constantly encountering younger wood while the descending hyphae encounter older wood. This theory is upheld by the fact that in the roots the greatest growth is toward the trunk.

INOCULATIONS IN STUBS

In the stub inoculations (those which were made by cutting off a branch 10 to 12 inches above its base and placing the inoculum over the entire cut surface), the relative amount of growth in tissues of different ages as indicated in table 6 corresponds very closely with the data given in table 5. In stub inoculations, however, the growth is much more rapid owing to the death of the tissues, caused by removing the foliage. Almost as rapid growth was secured by keeping the foliage removed from branches which had been inoculated. In table 6 the number of rings of annual growth free from infection is given. This shows the radial distribution of the mycelium 5 and 10 inches from the point of inoculation. It was impossible to show the longitudinal distribution owing to the fact that the mycelium had entered the trunk of the trees.

Very few conspicuous cankers were produced by inoculations where the limbs were not injured in some way. In the stub inoculations, the first infection usually occurred close to the center of the wound and the mycelium proceeded rapidly toward the trunk. The newer wood and finally the bark was invaded beginning at the end of the stub and extending toward

the trunk. When the cankered area reached the trunk there was no further external evidence of growth until the mycelium had invaded the outer rings of wood in the trunk when the cankered area was again enlarged.

INOCULATIONS IN TREES OF DIFFERENT AGES

A number of inoculations were made in young trees of different ages to ascertain if susceptibility to attack by blister canker was in any way associated with the age of the trees. Trees of several varieties ranging from one to four years of age at the time of inoculation were used. The data in table 7 indicate that, as in the case of inoculations in limbs of mature trees, the age of the wood inoculated is a more important factor than the age of the tree.

ROOT INOCULATIONS

Inoculations with ascospores were made in the roots of Ben Davis and Jonathan trees. The roots were uncovered, and inoculated in the manner already described. Wires were attached which would reach above the surface of the ground and zinc labels attached. The soil was then replaced. The data in table 8 show the results of these inoculations.

The mycelium travels much slower thru the roots than thru the upper portion of the tree. That this is not altogether due to the cellular structure is shown by the fact that in a number of the roots examined the tracheae are much more numerous and are larger than in the trunk and limbs. However, pits in the cell walls of the roots examined were not so numerous as in the cell walls of tissues in the branches. That cellular structure does modify the rate of growth to some extent is shown by the fact that the mycelium passes very slowly and with difficulty thru the region of the crown of the tree where the cells are greatly distorted and compressed. It was noted that this was true whether the infection came from the branches or the roots. No doubt the growth in the roots is retarded to some extent on account of lack of oxygen. That this must be true is shown by the slower growth of mycelium made in roots situated rather deep in the soil, while in those at or near the surface the growth was found to be almost as rapid as in the trunk and branches. Growth may also be retarded by the abundance of sap in the roots. The severing of a root at or just beyond the inoculation caused the growth of mycelium to be much more rapid, and as will be shown later the checking of absorption of water by increasing the osmotic

pressure of the solution surrounding the roots rendered them very susceptible indeed.

Table 8 shows that the older tissues are the most susceptible to infection. A number of inoculations were also made in roots of young trees in jars. It was found that one-year-old roots became infected with difficulty and then only when near the surface of the soil. In such infections the growth of the mycelium was very slow. Mycelial growth in the region of the crown of the tree progressed more rapidly in young than

TABLE 8—*Rate of growth of mycelium above and below inoculations in roots*

VARIETY	Inoculated in Xylem		Inoculated at Cambium	
	Above	Below	Above	Below
	Inches	Inches	Inches	Inches
Ben Davis	24.0	31.5	22.0	26.0
	21.5	20.0	18.5	24.5
	37.0	25.5	14.0	12.5
	48.5	51.0	8.0	11.0
	37.5	46.5	17.0	15.5
	42.0	31.5	7.5	6.5
	58.5	29.0	12.5	10.0
	3.0	11.0	1.5	2.0
	3.0	3.5	2.0	2.0
	2.5	3.0	2.0	2.5
	4.0	1.5	1.5	1.0
	14.0	13.5	11.5	16.0
	21.0	20.5	14.0	10.5
	11.0	15.0	....	....
Average	23.39	21.62	10.15	10.77
Jonathan	2.0	2.5	2.0	3.0
	3.0	3.0	2.0	3.5
	3.5	6.5	3.0	3.5
	3.5	5.0	1.5	1.5
	18.0	26.5	3.5	5.0
	21.0	16.0	1.0	1.5
	42.5	36.0	3.5	2.0
	2.0	4.0	3.0	3.0
	10.5	11.5	2.5	2.5
	6.0	7.0	2.5	1.0
	8.5	12.0	1.5	1.0
	3.0	1.5	....	....
	5.5	4.5	....	....
	10.0	6.5	....	....
	14.0	7.5	....	....
Average	10.20	10.00	2.36	2.50

in old trees. In young trees the cells in this region are not so distorted and compressed as in mature trees.

SEASONAL SUSCEPTIBILITY

An attempt was made to determine at what season of the year trees are most susceptible to infection. Inoculations were made in two-year-old trees and in branches of mature trees, the branches ranging from one-half to one inch in diameter. The inoculations were made at about the same date in May, June, July, and August, respectively. All were examined at the same time the following winter. The data secured (table 9) are rather contradictory in that inoculations made in May in young trees made slightly less total growth than similar inocu-

TABLE 9—*Comparison of rate of growth of mycelium from inoculations made at different seasons of the year*

DATE INOCULATED	Two-Year-Old Trees		One-Inch Wood of Mature Trees	
	Above	Below	Above	Below
	Inches	Inches	Inches	Inches
May 20-25	4.0	12.5	8.5	19.0
	2.0	8.5	8.0	20.5
	5.0	11.5	3.0	7.0
	3.0	7.5	12.0	13.5
	3.0	7.5	7.0	11.0
	1.5	3.5	5.5	9.5
	2.5	4.0	11.0	21.5
	2.5	7.0	16.0	14.0
	2.0	4.5	10.5	23.5
	2.5	7.5	5.0	9.5
	....	....	18.0	41.0
Average	2.80	7.40	9.50	17.27
June 22-28	12.0	15.0	10.0	15.0
	12.0	12.5	10.0	20.0
	6.5	8.5	23.5	28.0
	2.0	6.5	12.0	18.0
	2.5	5.5	21.0	19.0
	1.5	5.0	12.0	14.0
	2.5	4.0	7.0	8.5
	2.0	6.5	13.0	15.0
	2.0	2.5	10.0	10.0
	2.5	5.0	10.0	12.0
	1.5	2.5	8.0	6.0
	....	....	6.0	14.0
Average	4.27	6.68	11.87	14.96

TABLE 9—*(Continued)—Comparison of rate of growth of mycelium from inoculations made at different seasons of the year*

DATE INOCULATED	Two-Year-Old Trees		One-Inch Wood of Mature Trees	
	Above	Below	Above	Below
	Inches	Inches	Inches	Inches
July 15-20	1.5	1.5	9.0	14.0
	1.5	2.5	9.0	6.5
	8.0	12.0	14.0	30.0
	2.0	3.0	5.5	13.0
	4.5	6.0	16.0	24.0
	2.0	4.0	14.0	25.0
	4.0	8.0	5.5	6.0
	1.0	3.5	14.0	16.0
	6.5	8.0	11.0	6.5
	2.0	6.5	4.0	7.5
	1.0	2.5	24.5	31.0
	....	....	18.0	22.0
Average	3.09	5.23	12.04	16.79
Aug. 23-28	9.0	4.5	7.0	7.5
	8.0	9.0	3.0	11.0
	1.5	2.5	3.5	6.0
	3.0	4.5	14.0	19.5
	6.0	4.5	12.5	15.0
	7.0	8.0	12.0	18.0
	2.5	6.0	12.0	14.0
	4.0	6.0	6.0	18.0
	3.5	5.5	5.0	10.0
	4.0	7.0	4.5	12.0
	1.5	2.0	12.0	30.0
	1.0	1.5	14.0	12.0
Average	4.25	5.08	8.79	14.42

lations made in June. The average growth of June inoculations in branches of mature trees was no greater than that of July inoculations. The July inoculations in young trees averaged less growth than the August inoculations. Ben Davis trees of equal size and vigor were used in both series. The writer is unable to explain the much more rapid growth from inoculations made in late summer. It could not have been because the spores were more virile late in the summer since half of the inoculations in each case were made with pure culture. Hence the trees must have been more susceptible at that time. However, if this is true, it does not explain why the late inoculations made such a phenomenal growth compared to the infections which had the whole season in which to grow.

During the winter of 1916-1917 a number of two-year-old trees were planted in large jars in the greenhouse. A group of 10 were inoculated just as soon as set, 10 more four weeks later just as the buds were swelling, and an equal number as soon as the trees were in full leaf, which was about five weeks after the second series. They were examined fourteen weeks after the first inoculations were made. The average growth in the first series was 18.75 inches above and 20.75 inches below the inoculations, or a total of 49.5 inches. This was an average of slightly over 3.5 inches per week. The second series made an average growth of 8.2 inches above and 9.5 inches below, or a total average of 17.7 inches. This was an average of 1.77 inches per week. The third series made when the trees were in full leaf showed an average growth of 1.37 inches above and 1.45 inches below, or a total average of 2.82 inches. This was an average of 0.56 inch per week. The data thus far indicate that the mycelium makes its most rapid progress during the season when the tree is making little growth. Whether the slow growth is due to the retarding influence of an abundance of water and a lack of air or whether rapid growth is due to the presence in the tissues of stored food materials, the writer has been unable to determine.

EFFECT OF SOIL MOISTURE ON SUSCEPTIBILITY

An effort was made to ascertain the relation of the amount of moisture in the soil to susceptibility to blister canker. Oil barrels were secured and sawed thru half way between the heads. Each end made a large tub. The oil was burned out and the tubs set in the ground so that only about three inches of the top remained above the surface. The trees were planted in soil in these tubs which were covered with a flat cone of rubberoid roofing to exclude rain. Water was prevented from running in at the hole around the tree trunk by a shield of potter's clay.

In one series the soil was kept saturated, in another the water content of the soil was kept at the optimum for normal growth, while in the third only enough water was supplied to keep the trees from dying.

In the saturated series all of the trees soon died so that no data could be secured. The data from the other series are given in table 10.

There was considerable variation in the individual trees of the same series, and in several cases trees with an optimum

TABLE 10—*Effect of moisture content of soil on resistance of young trees*

Variety	Region Inoculated	2-Year-Old Trees: Distance Disease Progressed, Trees in Dry Soil: Above	2-Year-Old Trees: Dry Soil: Below	2-Year-Old Trees: Distance Disease Progressed, Trees in Wet Soil: Above	2-Year-Old Trees: Wet Soil: Below	1-Year-Old Trees: Distance Disease Progressed, Trees in Dry Soil: Above	1-Year-Old Trees: Dry Soil: Below	1-Year-Old Trees: Distance Disease Progressed, Trees in Wet Soil: Above	1-Year-Old Trees: Wet Soil: Below
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Ben Davis	Trunk	36.0	28.0	9.0	4.5	30.0	30.5	6.0	4.5
		40.0	24.5	8.5	9.0	31.5	33.0	7.0	8.0
		29.5	31.5	11.5	12.0	....	....	3.0	5.5
	Average	35.17	28.00	9.67	8.50	30.75	31.75	5.33	6.00
	1-year-old branches	5.5	8.5	1.0	2.5	3.0	3.0	1.0	1.0
		7.5	11.0	....	....	4.0	5.0	1.0	1.5
		3.5	9.0	1.0	1.0	3.0	4.5	0.5	1.0
	Average	5.50	9.50	1.00	1.75	3.33	4.17	0.83	1.17
	Trunk*	3.0	7.5	2.5	4.0	....	....	....	....
		2.5	7.0	2.5	7.5	....	....	....	....
		4.0	8.0	1.5	2.5	....	....	....	....
	Average	3.17	7.50	2.17	4.67				
	1-year-old branches*	6.5	8.5	1.0	2.5	....	....	....	....
		2.5	6.0	3.5	5.5	....	....	....	....
		4.0	7.0	1.5	1.5	....	....	....	....
	Average	4.33	7.17	2.00	3.17				

*Trees inoculated May 22, 1916, examined November 1, 1916. All others inoculated August 23, 1915, examined April 15, 1916.

TABLE 10—*(Continued)*—*Effect of moisture content of soil on resistance of young trees*

VARIETY	Region Inoculated	2-YEAR-OLD TREES				1-YEAR-OLD TREES			
		Distance Disease Progressed, Trees in Dry Soil		Distance Disease Progressed, Trees in Wet Soil		Distance Disease Progressed, Trees in Dry Soil		Distance Disease Progressed, Trees in Wet Soil	
		Above	Below	Above	Below	Above	Below	Above	Below
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Jonathan	Trunk	4.0	6.0	4.0	4.0	3.5	3.0	2.0	10.5
		3.0	8.5	8.5	9.0	6.5	6.0	1.5	1.5
		6.5	8.0	2.5	6.5	4.0	2.5	....	....
	Average	4.50	7.50	5.00	6.50	4.67	3.83	1.75	6.00
	1-year-old branches	3.0	4.0	5.5	4.0	2.5	3.5	2.0	3.5
		12.5	14.0	3.0	4.0	0.5	0.5	....	....
		2.5	3.5	6.5	14.5	2.0	2.0	4.0	4.0
	Average	6.00	7.17	5.00	7.50	1.67	2.00	3.00	3.75
N. W. Greening	Trunk	....	....	4.0	6.0	6.0	6.5	2.5	4.5
		10.0	10.5	6.5	10.0	3.0	4.5	1.0	3.5
		6.0	6.0	2.0	4.5	1.5	2.0	1.5	2.0
	Average	8.00	8.25	4.17	6.83	3.50	4.33	1.67	3.33
	1-year-old branches	2.0	3.5	2.0	5.0	2.5	2.0	2.5	4.0
		1.5	2.5	3.5	4.5	1.0	1.0	1.5	1.5
		1.0	1.0	4.0	5.5	2.5	4.5	....	....
	Average	1.50	2.33	3.17	5.00	2.00	2.50	2.00	2.75

TABLE 10—*(Continued)—Effect of moisture content of soil on resistance of young trees*

VARIETY	Region Inoculated	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Above	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Below	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Above	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Below	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Above	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Below	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Above	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Below
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Delicious	Trunk	14.5	15.0	2.5	2.5	13.5	15.0	4.5	8.5
		15.5	14.5	6.0	7.0	14.5	18.5	8.0	10.0
		14.5	15.0	4.5	5.5	12.5	18.5	4.5	8.0
	Average	14.83	14.83	4.33	5.00	13.50	17.33	5.67	8.83
	1-year-old branches	3.5	6.0	2.5	6.0	2.0	2.5	4.0	4.5
		2.5	3.0	8.0	14.0	2.5	3.0	4.5	5.0
		....	....	4.5	8.5	2.5	3.0	....	....
	Average	3.00	4.50	5.00	9.50	2.33	2.83	4.25	4.75
Winesap	Trunk	18.0	18.0	4.0	5.0	2.0	2.0	4.0	4.0
		16.5	16.0	3.5	7.0	3.0	3.0	4.5	5.5
		15.0	18.0	2.5	4.0	3.0	3.0	2.5	3.0
	Average	16.50	17.33	3.33	5.33	2.67	2.67	3.67	4.17
	1-year-old branches	1.5	2.5	4.0	4.5	....	....	3.0	2.0
		2.0	2.0	3.5	3.0	2.5	3.0	3.0	3.0
		2.0	2.0	3.0	3.5	2.5	3.0	2.5	3.0
	Average	1.83	2.17	3.50	3.67	2.50	3.00	2.83	2.67

TABLE 10—*(Concluded)—Effect of moisture content of soil on resistance of young trees*

VARIETY	Region Inoculated	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Above	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Below	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Above	2-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Below	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Above	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Dry Soil: Below	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Above	1-YEAR-OLD TREES: Distance Disease Progressed, Trees in Wet Soil: Below
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
York	Trunk	7.0	4.5	3.5	3.5	...	...	4.5	4.0
		3.0	3.0	3.0	3.0	...	...	5.0	7.5
		...	...	4.0	4.0	10.0	10.0	4.5	6.0
	Average	5.00	3.75	3.50	3.50	10.00	10.00	4.67	5.83
	1-year-old branches	3.0	5.0	1.5	3.0	1.5	1.0	2.0	3.5
		2.0	4.0	2.0	4.0	3.0	3.5	3.5	1.0
		2.0	3.5	5.0	1.5	2.0	4.0	2.0	1.0
	Average	2.33	4.17	2.83	2.83	2.17	2.83	2.50	1.83
Ben Davis	Main root	9.5	...	1.5	...	...	...	...	...
		39.0	...	5.0	...	...	...	...	...
		38.75	...	6.25	...	...	...	...	...
		28.5	...	...	...	...	...	...	...
		14.25	...	2.5	...	...	...	...	...
	Average	26.00	...	3.81	...	...	...	...	...

supply of water proved more susceptible than those with too little water. In the majority of instances, however, there was less fungous growth in the trees which received the proper supply of moisture. The average of all the inoculations in the two series shows a greater growth in the trees lacking water. When the inoculations were examined the amount of terminal growth made by the trees was measured. The average growth was 16.5 inches per tree for the optimum series and 4.35 inches for the dry series. This would indicate that conditions which contribute to the vigor of the tree tend to inhibit fungous growth.

A number of water sprouts which had made a growth of over three feet in one season were removed and sections 12 inches long inoculated and placed in closed cylinders. An equal number of one-year-old branches of terminal growth which had made a growth of only 12 to 14 inches were inoculated in a like manner. Fungous growth was much more rapid in the water sprouts than in the terminal growth. This may have been because the tracheae in the former were very large and numerous.

RELATION OF AVAILABLE NUTRIENTS TO SUSCEPTIBILITY

To determine the effect of different concentrations of mineral nutrients and of depriving the trees of certain elements, trees were planted in pure river sand and supplied with a nutrient solution. The complete nutrient solution was used at a concentration of 0.1 per cent, 0.2 per cent, 0.4 per cent and 0.6 per cent, respectively. Other groups of trees were supplied with the complete nutrient solution minus nitrogen, potassium, phosphorus, magnesium, and calcium. These solutions with one element lacking were used at a concentration of 0.2 per cent.

The solution was administered at the bottom of the jars thru a rubber tube attached to a smaller jar. The bottoms of the feeding jar and the one containing the tree were on the same plane so that the height of the liquid in the feeding jar would indicate the height of the water table in the other jar.

A fine screen was placed over the opening on the inside of the large jar to keep the hose from being clogged. Two inches of coarse gravel was first placed in the bottom of the jar which was then filled to within two inches of the top with river sand. The tree was put in place as the jar was filled. Two inches of clean gravel was placed over the sand and the whole cov-

ered with rubberoid roofing as in the case of the tubs already mentioned, to prevent evaporation and a consequent concentration of the nutrient solution.

A record was kept of the amount of solution used by each tree and the amount of growth made. Table 11 shows the relative amount of fungous growth for trees in each solution compared with the amount in trees which were inoculated at the same time and set in soil.

The least infection was found in trees set in soil. These trees made a much more satisfactory growth than any of the trees supplied with nutrient solutions. Of the trees supplied with nutrient solutions those receiving a 0.2 per cent complete solution made the most satisfactory growth and showed the least infection. Trees grown in solutions of higher concentration (0.4 per cent and 0.6 per cent) were badly infected and made little growth.

The osmotic pressure of the 0.6 per cent solution was so great that it was impossible for the trees to obtain sufficient water to maintain growth. All but one of the trees lost their leaves and were practically dead above and below inoculations. The same conditions obtained, but to a lesser degree, for the trees in 0.4 per cent solution. The trees in 0.1 per cent solution made little growth but, except for a stunted appearance, remained apparently healthy. They were more heavily infected than the trees in soil or those receiving the 0.2 per cent solution.

There was so much variation in the amount of infection and such a difference in the amount of growth made by the individual trees that no reliable conclusions can be drawn. All of the trees made some but in no case a satisfactory growth. Even the trees with no nitrogen made considerable leaf growth altho there was practically no root growth. The only definite statement which can be made is that the greatest infection was always found in trees which had made the least growth.

The supply hose in one of the jars became clogged. This was not noticed until several days later when the feeding jars were being replenished. It was noticed that none of the solution in this jar had been used, and that the leaves of the tree were wilting. The obstruction was removed but the tree did not recover. The hose in three other jars were then stopped for five days with like results. All of these trees (indicated in table 11 by *) were as badly infected as those grown in the solutions of high concentration.

TABLE 11—*Effect of varying amounts of available soil nutrients upon rate of growth of mycelium*

NUTRIENT SOLUTION USED	1915†		1916‡		TOTAL
	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches
Complete at 0.1 per cent	13.0	11.0	31.0*	28.0	
	1.0	6.5	9.5	14.5	
	11.0	19.0			144.5
Average	8.33	12.17	20.25	21.25	
Complete at 0.2 per cent	9.0	17.0	5.0	15.5	
	8.0	24.0	9.5	18.0	
	9.0	3.0			118.0
Average	8.67	14.67	7.25	16.75	
Complete at 0.4 per cent	26.0*	31.0			
	20.0	30.0	15.0*	25.5	
	32.0	21.0	38.0	21.0	259.5
Average	26.0	27.33	26.5	23.25	
Complete at 0.6 per cent	30.0	20.0			
	28.0	16.0	30.0	15.5	
	27.0*	21.0	36.0*	24.5	248.0
Average	28.33	19.0	33.0	20.0	
Complete, minus nitrogen at 0.1 per cent	14.0	19.0			
	9.5	20.0	9.0	5.0	
	7.0	18.5	34.0	25.0	161.0
Average	10.17	19.17	21.50	15.00	

†Inoculated February 9. Examined April 15. Grown in jars in greenhouse.
‡Grown outside in jars, inoculated May 22, and examined November 1, 1916.
*Trees killed.

TABLE 11—*(Continued)*—*Effect of varying amounts of available soil nutrients upon rate of growth of mycelium*

NUTRIENT SOLUTION USED	1915†		1916‡		TOTAL
	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches
Complete, minus phosphorus at 0.2 per cent	15.0	23.0			
	9.0	21.5	3.0	2.5	
	12.5	31.0	7.0	5.5	130.0
Average	12.17	25.17	5.00	4.00	
Complete, minus potassium at 0.2 per cent	28.0	24.5			
	19.0	29.0	8.0	15.0	
	21.0	34.0	37.0*	19.0	234.5
Average	22.67	29.17	22.50	17.00	
Complete, minus magnesium at 0.2 per cent	19.0	19.0			
	21.0	28.0	7.5	12.5	
	19.0	27.0	5.5	8.5	167.0
Average	19.67	24.67	6.50	10.50	
Complete, minus calcium at 0.2 per cent	34.0	14.0			
	22.0	21.0	4.5	9.0	
	16.0	30.5	30.5*	27.0	208.5
Average	24.00	21.83	17.50	18.00	
Grown in soil	9.0	4.5	2.5	7.0	
	8.5	9.0	2.0	4.5	
	11.5	12.5			71.0
Average	9.67	8.67	2.25	5.75	

†Inoculated February 9. Examined April 15. Grown in jars in greenhouse.
‡Grown outside in jars, inoculated May 22, and examined November 1, 1916.
*Trees killed.

Later, trees were planted in jars of soil and watered from the top. Four grams of nitrogen, potassium, phosphorus, calcium and magnesium, respectively, were added in a 0.2 per cent solution weekly to a series of four jars each. The trees were inoculated as soon as they were in full leaf. They were examined ten weeks later but no appreciable difference could be found in the amount of infection. The trees which received nitrogen made a slightly faster growth, but there was no difference in amount of growth made by the others.

In the spring of 1915 two fourteen-year-old Ben Davis and two Jonathan trees of the same age were inoculated. A trench four feet deep was dug around each tree, close enough to remove approximately one-third of the feeding roots. The inner wall was lined with tar paper to prevent a rapid growth of roots out into the soft wet soil with which the ditches were filled.

The trees made very little growth but each bore a crop of undersized fruit. The leaves turned yellow and fell long before the surrounding trees shed their leaves. In 1916 both Jonathan trees bore a light crop but made little growth. One of the Ben Davis trees did not bear any fruit and the other only a few small apples. The leaves appeared yellow and wilted thruout the season. Several characteristic cankers were formed.

When the inoculations were examined it was found that all of the heartwood and all of the sapwood except the two outer rings in the Ben Davis trees was infected, and in many instances all of the wood was infected, so that no data could be secured on the amount of fungous growth except to note the amount of wood still intact. The Jonathan trees were likewise found to be so badly infected that few reliable data could be secured. However, the fungus had made much slower lateral progress than in the Ben Davis trees as shown by sectioning the wood of the trunk and limbs.

The comparative amount of infection is shown in plates XIV and XV.

VARIETAL SUSCEPTIBILITY

A great deal of variation is shown in the susceptibility of different varieties of apples to blister canker. There is also considerable variation within each variety. The data given in table 12 while not conclusive give a fairly reliable indication of the comparative susceptibility of the different varieties. These data do not agree in all cases with field observations.

Field observations indicate that varieties such as Missouri, Janet, and Maiden Blush are comparatively less susceptible than conclusions drawn from table 12 would indicate. In the main, however, field observations and inoculation data correspond quite closely. The inoculations in this series were all made in the heartwood during the same week and were examined at the same time.

It was noted in examining young trees which had been inoculated that when the varieties were on their own roots the susceptibility of the roots corresponded to that of the tops, but in budded trees where all of the roots had come from the seedling stock the roots showed all degrees of susceptibility ranging from great resistance to great susceptibility.

There was less difference in the percentage of inoculations which proved effective in the different varieties than in the comparative amount of growth made by the effective inoculations. The difference was most noticeable where inoculations were made in active xylem. The percentage of effective inoculations was high in all varieties where the inoculations were made in the heartwood. On account of having a very limited number of trees of many of the different varieties it was impossible to make enough inoculations to furnish satisfactory data on this phase of the subject.

According to the data given above and field observations the varieties are tentatively grouped as follows:

Very Resistant	Moderately Resistant	Moderately Susceptible	Very Susceptible
Oldenburg	Jonathan	York	Delicious
Wealthy	Winesap	Willow Twig	Ben Davis
	Arkansas	Rome Beauty	Gano
	Arkansas Black	Maiden Blush	Yellow Transparent
	Janet	Champion	
	Minkler	Grimes	
	Fameuse (Snow)	Missouri	
	Stayman Winesap	Northern Spy	
	Virginia Beauty	Chicago	
	Wolf River	Yates	
	Northwest Greening	King David	
	Malinda	Walbridge	

Susceptibility may and no doubt does vary in different localities and under different conditions as does susceptibility to apple scab and apple blotch (Cooper[5]). Variation in suscep-

TABLE 12—*Varietal susceptibility as shown by a comparison of rate of growth of mycelium above and below inoculations in wood of different varieties*

VARIETY	¼ Inch Wood		½ Inch Wood		¾ Inch Wood		1 Inch Wood		2 Inch Wood		Total Average for Variety
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Ben Davis	1.0	2.0	2.0	2.5	5.0	10.0	25.0	47.0	44.5	39.0	
	2.0	4.0	12.0	18.0	2.5	2.5	32.0	46.0	59.0	58.5	
	1.0	1.0	3.0	12.0	13.5	14.5	6.0	18.0	38.5	42.5	
	2.0	2.0	11.0	25.5	29.0	31.0	29.0	38.0	62.5	70.0	
	1.0	1.5	10.5	36.0	13.0	15.5	24.5	29.0			
	1.0	1.0	12.0	30.0	6.5	14.5	21.5	32.0			
	0.0	1.0	9.0	9.5	16.0	24.0	36.0	21.5			
	2.0	2.0			8.5	16.5	28.5	29.0			
	4.0	3.5			25.0	30.5	28.0	24.5			
	5.0	8.0					50.0	49.0			
Average	1.90	2.60	8.50	19.07	13.22	17.67	28.05	33.40	51.12	52.50	22.80
Jonathan	1.5	2.0	6.0	4.5	5.0	3.0	6.5	8.5	26.0	38.0	
	3.0	3.0	3.5	6.0	8.0	6.0	16.5	27.5	28.0	22.5	
	2.5	2.0	2.0	2.5	8.0	16.0	39.0	41.5	21.5	32.0	
			3.0	7.0	1.0	1.5	17.0	19.0	39.0	31.5	
			6.0	6.0	4.0	4.5	20.0	21.5			
			2.5	2.0	1.5	2.0	6.0	12.0			
			3.0	3.5	13.0	10.5	18.0	20.0			
			2.0	2.0	12.0	14.0	18.5	21.0			
			12.0	10.5	3.0	3.0					
			3.0	2.0	5.0	6.0					
			10.0	24.0							
Average	2.33	2.33	4.82	6.37	6.05	6.65	17.7	21.37	31.01	31.0	12.97

TABLE 12—*(Continued)—Varietal susceptibility as shown by a comparison of rate of growth of mycelium above and below inoculations in wood of different varieties*

VARIETY	¼ Inch Wood		½ Inch Wood		¾ Inch Wood		1 Inch Wood		2 Inch Wood		Total Average for Variety
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Winesap	1.0	1.0	10.0	4.5	6.5	10.0	36.0	41.0	49.0	43.0	
	0.0	1.0	8.5	21.0	8.0	6.0	16.0	10.0	49.0	42.5	
	2.0	2.0	3.5	6.0	5.0	3.5	8.5	11.5	16.5	24.0	
	....	....	....	....	5.5	10.0	15.0	13.5	....	....	
Average	1.0	1.33	7.33	10.50	6.25	7.37	18.87	19.00	38.17	36.50	14.63
Delicious	10.5	16.0	14.0	25.0	16.0	24.0	28.5	26.0	59.0	56.5	
	8.0	12.5	13.5	18.0	36.5	36.0	20.5	31.5	41.0	52.0	
	....	....	....	....	15.0	19.5	....	....	36.5	44.5	
Average	9.25	14.25	13.75	21.50	22.5	26.50	24.50	28.75	45.50	51.00	25.75
Grimes	2.0	2.0	10.0	10.5	14.0	12.5	37.0	51.5	45.0	54.0	
	2.0	2.0	13.5	14.0	14.0	20.0	14.5	28.0	39.0	31.5	
	1.5	2.0	5.5	6.5	5.5	17.0	12.0	15.5	31.5	45.5	
	2.0	2.0	15.0	15.5	6.5	8.5	6.5	15.0	48.0	47.0	
	....	....	....	....	8.5	14.0	....	....	35.0	47.0	
Average	1.87	2.00	11.00	11.62	9.70	14.4	17.50	27.50	39.70	45.0	18.03
York	3.5	4.0	3.0	3.5	14.0	24.0	11.5	18.0	30.0	41.0	
	1.0	1.0	3.0	3.5	8.5	12.5	23.0	27.5	44.0	47.5	
	2.0	1.5	....	....	5.0	5.5	12.5	11.0	....	....	
Average	2.17	2.17	3.00	3.50	9.17	14.00	15.67	18.83	37.00	44.25	14.97

TABLE 12—*(Continued)—Varietal susceptibility as shown by a comparison of rate of growth of mycelium above and below inoculations in wood of different varieties*

VARIETY	¼ Inch Wood		½ Inch Wood		¾ Inch Wood		1 Inch Wood		2 Inch Wood		Total Average for Variety
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Ingram			2.0	2.0	3.0	3.0	12.0	12.0	23.0	24.5	
					4.0	6.0					
Average			2.00	2.00	3.50	4.50	12.00	12.00	23.00	24.50	10.44
Janet	3.0	3.0	6.0	11.0	4.0	8.0	28.0	37.0	35.0	40.0	
			8.0	10.5	7.0	8.0	37.0	21.0	29.0	38.0	
Average	3.00	3.00	7.00	10.75	5.50	8.00	32.50	29.00	32.00	39.00	16.97
Prairie Crab	1.75	1.5			2.0	1.5	3.0	4.5	12.0	16.5	
		1.0			4.5	3.0	4.5	3.0	9.5	11.0	
Average	1.75	1.25			3.25	2.25	3.75	3.75	10.75	13.75	5.06
Malinda	1.0	1.0			4.0	2.5	5.5	10.0	14.0	16.0	
					4.0	2.5	4.5	5.5			
					2.5	4.0					
					4.5	7.0					
Average	1.00	1.00			3.75	4.00	5.00	7.75	14.00	16.00	6.56
Willow Twig			2.0	3.0	3.0	3.0	10.0	18.0			
			3.0	3.0	6.0	6.0	8.0	14.0			
			2.0	8.0							
Average			2.33	4.66	4.50	4.50	9.00	16.00			6.83

TABLE 12—*(Continued)—Varietal susceptibility as shown by a comparison of rate of growth of mycelium above and below inoculations in wood of different varieties*

VARIETY	¼ Inch Wood		½ Inch Wood		¾ Inch Wood		1 Inch Wood		2 Inch Wood		Total Average for Variety
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Duchess	....	....	....	....	....	....	2.0	2.0	2.0	2.0	
	....	....	....	....	....	....	2.0	3.0	5.0	8.0	
	....	....	....	....	....	....	3.0	3.0	12.0	14.5	
Average	....	....	....	....	....	....	2.33	2.67	6.33	8.17	4.87
Missouri	2.0	3.0	14.0	18.0	37.0	59.0	28.0	36.5	20.5	31.0	
	3.0	3.0	17.0	20.5	30.0	40.0	56.0	60.0	40.5	51.0	
Average	2.50	3.00	15.50	19.25	33.50	49.50	42.00	48.25	30.50	41.00	28.50
Roman Stem	....	....	2.0	2.0	2.0	5.0	....	....	8.5	8.0	
	....	....	....	....	2.0	2.0	....	....	18.5	24.0	
Average	....	....	2.00	2.00	2.00	3.50	....	....	13.50	16.00	6.50
Arkansas	1.0	1.0	1.0	1.0	8.0	8.5	21.0	14.0	23.0	24.0	
Average	1.00	1.00	1.00	1.00	8.00	8.50	21.00	14.00	23.00	24.00	10.25
King David	....	....	3.0	9.0	13.5	19.0	33.0	45.5	36.0	49.0	
	....	....	15.0	21.0	36.0	41.5	28.0	31.0	....	....	
Average	....	....	9.00	15.00	24.75	30.25	30.50	38.25	36.00	49.00	29.09

TABLE 12—*(Concluded)—Varietal susceptibility as shown by a comparison of rate of growth of mycelium above and below inoculations in wood of different varieties*

VARIETY	¼ Inch Wood		½ Inch Wood		¾ Inch Wood		1 Inch Wood		2 Inch Wood		Total Average for Variety
	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Champion	.....	.....	2.0	2.0	8.0	19.0	.....	.....	21.5	28.0	
	.....	.....	.....	.....	5.0	10.0	.....	.....	5.0	11.5	
	.....	.....	.....	.....	3.0	6.5	.....	.....	.....	.....	
Average	.....	.....	2.00	2.00	5.33	11.83	.....	.....	13.25	19.75	9.03
Wealthy	0.5	1.5	1.0	2.0	8.0	10.5	8.0	7.0	4.5	5.5	
	2.5	2.5	1.5	1.5	2.5	2.0	2.5	5.5	12.0	11.0	
	.....	.....	4.0	4.0	3.5	3.0	4.0	3.0	3.5	6.5	
	.....	.....	.....	.....	.....	.....	4.5	5.0	14.5	16.5	
Average	1.50	2.00	2.17	2.50	4.67	5.17	4.75	5.12	8.62	9.87	4.64
Whitney	0.0	1.0	.....	.....	13.0	14.0	10.0	12.5	6.5	17.0	
	.....	.....	.....	.....	.....	.....	12.0	36.5	12.0	14.0	
	.....	.....	.....	.....	.....	.....	.....	.....	16.5	40.0	
Average	0.00	1.00	.....	.....	13.00	14.00	11.00	24.50	11.67	23.67	12.35
Maiden Blush	.....	.....	2.5	7.0	14.0	28.0	21.5	22.0	57.5	61.0	
Average	.....	.....	2.50	7.00	14.00	28.0	21.50	22.00	57.50	61.00	26.69

tibility of apple trees to blister canker must be due to several factors. It is evident that structural differences influence to a great extent susceptibility to and amount of infection. That the degree of immunity is due in part to physiological factors can not be disputed and we may no doubt explain immunity in part by means of chemical differences.

Norton[14] designated anatomical or structural differences as the chief determiner of immunity of asparagus to rust. Ward[19] in a study of rust resistance in Bromes states he has concluded "that the matter has nothing to do with anatomy but depends entirely upon physiological reactions of the protoplasm of the fungus and of the cells of the host." Jones,[12] Giddings and Lutman do not believe that in the case of potato late blight, immunity is determined by either chemical or anatomical factors. Cobb[3] asserted that in the case of wheat rust anatomical hindrance plays an important part, but this is denied by Eriksson.[8] Cook and Taubenhaus[4] suggest that the presence of tannin in the cell sap influences to considerable extent susceptibility of trees to fungous diseases.

That immunity of apple trees to *Nummularia discreta* does depend to a large extent upon cellular structure or mechanical resistance is indicated by the fact that certain varieties which have been found very resistant were found on examination to have a cellular structure different from that of other varieties which are decidedly susceptible. Table 13 gives a comparison of the number, size, and thickness of cell walls, of tracheae, wood cells, and medullary ray cells in different varieties. By referring to table 12 it will be seen that varieties such as Delicious and Ben Davis are very susceptible, Winesap and Jonathan moderately resistant, and Oldenburg and Wealthy practically resistant. The table shows no constant difference in the number of tracheae present in a given area but the walls of the tracheae were found on an average to be thicker than in susceptible varieties. The wood cells which surround the tracheae were found to be considerably larger and thinner walled in susceptible varieties such as Delicious and Ben Davis than in resistant varieties such as Oldenburg and Duchess. A greater proportion of the cells were also found to have pitted walls and, since the hyphae must depend upon utilizing the pits as a means of passing from one cell to another, it follows that these varieties would be more susceptible. Perhaps the greatest difference in cell structure of the different varieties is in the number and size of the medullary ray cells. While there is no great difference in the shortest diameter of the cells they are considerably longer in Delicious and Ben

TABLE 13—*Comparison of number and size of cells and thickness of cell walls in susceptible and resistant varieties of apples*

VARIETY	TRACHEAE			WOOD CELLS		MEDULLARY RAY CELLS		
	No.	Diameter	Thickness of Wall	Diameter	Thickness of Wall	No.	Diameter	Thickness of Wall
		mm.	mm.	mm.	mm.		mm.	mm.
Delicious	35	.04488	.00204	.011475	.0033	151	.0150 x .0357	.00111
Ben Davis	31	.0468	.002295	.0114	.003419	139	.0150 x .03	.00105
Winesap	27	.03417	.003825	.00867	.00459	101	.0150 x .0204	.00204
Wealthy	31	.03468	.004131	.00765	.0051	83	.0150 x .0195	.00195
Oldenburg	37	.02703	.004182	.00816	.00561	76	.0[illegible]05 x .015	.00228
Prairie Crab	39	.03417	.003825	.00867	.00585	71	.0120 x .015	.00255

Davis than in the other varieties mentioned and have much thinner walls.

There is also decided difference in the relative size and number of cells in the tissues formed early in the season and those formed rather late in the fall. The earliest and most abundant infection is almost always found in the region of the larger cells, formed in the early spring growth. The comparative number of late thick-walled cells is much greater in the before mentioned resistant varieties.

In making cell measurements and counting cells the area covered under a high power objective was taken as standard. This measured 0.36 mm. in diameter. The tissues formed early in the spring and late in the fall of each annual ring formed during the last five seasons were examined in each variety. Five specimens of each variety were examined in each region, making a total of 50 examinations for each variety. The data shown in table 13 represent an average for all these measurements.

The number of medullary ray cells was determined from tangential wood sections. The different dimensions of the cells were determined by using both cross and tangential sections.

These data while of a preliminary nature show clearly that structural differences play no small part in influencing immunity of apple trees to *Nummularia discreta*.

It is also quite evident that immunity is influenced to some extent by physiological factors. The fungus progresses much more slowly in tissues where the protoplasm is still active. In fact the regions of the cambium and phloem are rarely if ever invaded until the tissues have been killed. As soon as the tissues are killed they are readily invaded as shown by both laboratory and field inoculations. This in itself does not account for the difference in degree of immunity of different varieties unless the age at which the cell content becomes inactive varies. There is a great variation in the age at which xylem tissues remain active in different species of trees but how much difference there may be in different species or subspecies and varieties of Malus has not been determined but is being studied by the writer at the present time.

By comparing the rate of growth of mycelium in tissues which were known to be active and those known to contain no protoplasm some interesting results were obtained. In securing these data 20 inoculations in one-year-old xylem of Ben Davis, Delicious, Jonathan, Winesap, Oldenburg, and Wealthy were examined. Ben Davis and Delicious were grouped to-

gether as susceptible, Jonathan and Winesap as moderately susceptible, and Oldenburg and Wealthy as resistant. A like number of inoculations in the heartwood of each variety were examined at the same time and grouped in the same way. Total growth above and below the inoculation was considered. There was a great deal of variation in the amount of growth made by the fungus in each variety, as shown by the data in table 14. In order to reduce the experimental error to a minimum much larger numbers should be employed than those used in securing the above data. However, considering the probable error the results clearly indicate that some factor or factors in addition to anatomical differences operate to influence immunity.

TABLE 14—*Relation of active and inactive tissues to varietal susceptibility*

GROUP	Average Growth in One-Year-Old Xylem	Range of Variation		Average Growth in Heart-wood	Range of Variation	
		Minimum	Maximum		Minimum	Maximum
	Inches	In.	In.	Inches	In.	In.
1. Susceptible	28.03	4.5	44.0	94.7	84.5	146.0
2. Moderately susceptible	9.8	2.5	36.5	65.2	51.0	92.0
3. Resistant	3.1	0.5	7.5	11.5	4.5	31.5

If no factors other than anatomical differences operate to influence the rate of growth, the fungus should make relatively as much growth in one tissue as another. Therefore, considering the rate of growth in inactive tissues of groups 1 and 2 as standard it would be expected, assuming 28.03 to be correct amount of growth in active tissue for group 1, that the amount of growth in group 2 would be 19.4 inches, but instead it is 9.8 inches. Considering groups 2 and 3 in the same way, the amount of growth in active tissue in group 3 should be 17.2 instead of 3.1 inches.

Branches of the different varieties sterilized by steam under pressure and then inoculated showed practically the same amount of growth in all xylem tissues. There was approximately the same difference between woods of different varieties as was shown in field inoculations in heartwood.

Branches were also notched deeply below the point of inoculation. In such cases the fungous growth was always more rapid than where the limbs were left intact.

The effect of cutting off the water and food supply of trees has already been discussed.

The foregoing data all indicate that both anatomical and physiological factors are concerned in modifying immunity to blister canker.

METHODS OF CONTROL

During the fall of 1912 a series of experiments was instituted to discover some means of controlling blister canker. One method was to cut out the canker. In doing this the cankered surface was removed and the discolored wood cut away until sound wood one inch deep surrounded the wound. Another was to remove the branch on which the canker was located. When it was found impracticable to remove the branch the canker was cut out. In cutting out a canker where too little sound wood surrounded the wound, the branch was removed.

A number of different disinfectants and covers were used on both kinds of wounds. They were so arranged that each cover would be used with every disinfectant in about the same number of treatments. Some wounds were left without covers and some without disinfectants.

A number of trees were pruned heavily at the time the cankers were treated while the remainder were left unpruned.

All treatments were numbered and records were made of the location, size, depth of cut (where the canker was cut out), and amount of sound wood between the discolored area and the surface of the bark.

At the end of the first season as indicated in table 15, it seemed that a high percentage of the treatments would prove effective since the wounds were healing nicely in the majority of cases and both trees and foliage appeared healthy. At the end of the second season, however, it was apparent that treating cankers according to any of the methods used would not prove satisfactory. In many instances the disease was visible in the bark at one or more points at the margin of the old treatment. On examining these treatments it was found that the disease appeared in the bark at points in the margin where the discolored wood was nearest to the surface at the time the treatment was given, or where for some reason the tissues

TABLE 15—*Showing efficiency of canker treatments 1, 2, 3, and 5 years after treatment**

DISINFECTANT	No. of Treatments	1913				1914			
		Effective		Not Effective		Effective		Not Effective	
		No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
1 Phenol	36	34	94.45	2	5.55	14	38.88	22	61.12
2 Mercuric chloride	20	20	100.0	0	0.0	9	45.0	11	55.0
3 Bordeaux 4-4-50	18	14	77.78	4	22.22	6	33.33	12	66.67
4 Copper sulphate	13	11	84.62	2	15.38	3	23.08	10	76.92
5 Formalin 10%	12	8	66.67	4	33.33	4	33.33	8	66.67
6 Formalin 20%	10	10	100.0	0	0.0	5	50.0	5	50.0
7 Formalin 40%	6	5	83.33	1	16.67	3	50.0	3	50.0
8 Lime sulphur 1.01 sp. gr	9	9	100.0	0	0.0	4	44.45	5	55.55
Check	4	......	......	4	100.0	......	......	4	100.0
Total	128	111	86.72	17	13.28	48	37.5	80	62.5
COVER									
1 Solid asphaltum	23	23	100.0	0	0.0	9	39.13	40	60.84
2 Liquid asphaltum dissolved in gasoline	11	9	81.82	2	18.18	3	27.27	8	72.73
3 Liquid asphaltum dissolved in linseed oil	18	15	83.33	3	16.67	8	44.45	10	55.55
4 Pine tar	13	11	84.62	2	15.38	3	23.08	10	76.92
5 Coal tar	13	13	100.00	0	0.00	5	38.46	8	61.54
6 White lead and oil	14	12	85.72	2	14.28	8	57.13	6	42.87
7 Venetian red and oil	16	14	87.50	2	12.50	6	37.50	10	62.50
8 Grafting wax	10	10	100.00	0	0.00	2	20.0	8	80.0
Check	10	4	40.00	6	60.00	4	40.0	6	60.0
Total	128	111	86.72	17	13.28	48	37.5	80	62.5

*All treatments represented in this table were made in 1912. Dates at the top indicate when examinations were made.

TABLE 15—*(Continued)*—*Showing efficiency of canker treatments 1, 2, 3 and 5 years after treatment**

DISINFECTANT	No. of Treatments	1915				1917			
		Effective		Not Effective		Effective		Not Effective	
		No.	Per Cent	No.	Per Cent	No.	Per Cent	No.	Per Cent
1 Phenol	36	12	33.33	24	66.67	5	13.88	31	86.12
2 Mercuric chloride	20	5	25.00	15	75.00	4	20.0	16	80.00
3 Bordeaux 4-4-50	18	3	16.67	15	83.33	3	16.67	15	83.33
4 Copper sulphate	13	3	23.08	10	76.92	0	0.00	13	100.00
5 Formalin 10%	12	2	16.68	10	83.32	2	16.68	10	83.32
6 Formalin 20%	10	2	20.00	8	80.00	0	0.00	10	100.00
7 Formalin 40%	6	2	33.33	4	66.67	1	16.67	5	83.33
8 Lime sulphur 1.01 sp. gr.	9	0	0.00	9	100.00	0	0.00	9	100.00
Check	4	0	0.00	4	100.00	0	0.00	4	100.00
Total	128	29	22.65	99	77.35	15	11.72	113	88.28
COVER									
1 Solid asphaltum	23	3	13.05	20	86.95	3	13.05	20	86.95
2 Liquid asphaltum dissolved in gasoline	11	2	18.18	9	81.82	2	18.18	9	81.82
3 Liquid asphaltum dissolved in linseed oil	18	6	33.33	12	66.67	3	16.67	15	83.33
4 Pine tar	13	2	15.38	11	84.62	2	15.38	11	84.62
5 Coal tar	13	4	30.77	9	69.23	2	15.38	11	84.62
6 White lead and oil	14	6	42.87	8	57.13	2	14.28	12	85.72
7 Venetian red and oil	16	4	25.0	12	75.0	1	6.25	15	93.75
8 Grafting wax	10	1	10.0	9	90.0	0	0.0	10	100.0
Check	10	1	10.0	9	90.0	0	0.0	10	100.0
Total	128	29	22.65	99	77.35	15	11.72	113	88.28

*All treatments represented in this table were made in 1912. Dates at the top indicate when examinations were made.

had not been sufficiently nourished. Where the cut was made straight across the top or bottom of the wound instead of being made pointed or where insufficient foliage was left on a branch to insure the proper amount of elaborated food materials to heal the wounds, cankers appeared almost invariably.

The unsatisfactory results led to the institution of the more fundamental experiments which have already been described, together with more minute observations of the treatments already made. New treatments were made each season as cankers appeared. The same methods were followed except that an effort was made to eliminate all discolored wood. In all cases the amount of wood free from discoloration was measured and the number of annual rings of growth represented was noted. In all 115 trees were treated. The total number of original treatments was 341. Of these 22 were re-treated three times, 105 were re-treated twice, and 214 were re-treated once. This totaled 831 treatments.

In so far as the beneficial effects of the various covers and disinfectants used are concerned table 15 may be taken as representative of the treatments made after 1912. Whether or not canker hyphae were left in the tissues at the time of treatment was found by close observation and microscopic examinations to be the determining factor. The effect of either covers or disinfectants was practically negligible where infected wood was left.

A number of artificial infections in young trees in the greenhouse were treated but not covered. In some the discolored strands were all removed while in others a small amount of the discolored wood was left. In all cases fungous growth continued from the remaining discolored wood while no evidence of the disease could be found in the trees where the discolored wood had all been removed.

It was found that the fungous growth was more rapid near the treatments than in similarly cankered limbs where no wounds were made. This was no doubt due to the fungus being able to secure oxygen more readily. A number of wounds were made in pairs in branches which contained mycelium close to the surface. One of each pair was disinfected and covered in the same way that canker wounds were treated while the other was tightly wrapped and waxed over to exclude air. In practically every case characteristic cankers formed about the wound which was not tightly wrapped. A few of the wrapped wounds also developed cankers, but such cankered

areas were much smaller than those which appeared at the unwrapped wounds.

Heavy pruning was found to be injurious rather than beneficial where the trees were heavily infected. While it induced more vigorous growth of the tree, it also exposed the mycelium of the fungus to the air wherever large wounds were made. Cankers almost invariably appeared at these pruning wounds within one or two seasons.

Radial growth of the fungus in badly infected trees was observed by cutting off large limbs at the trunk and noting both the amount of wood in inches and the number of annual rings free from the disease. It was noted that the fungus occupied about the same relative position in the trunk and larger limbs when the number of annual rings from the surface was considered. There was considerable variation in the amount of wood free from disease when measured in inches, due to the fact that some branches were much larger than others of the same age.

The fungus is not always confined to tissues of the same age. Most limbs grow faster and have a much thicker annual growth on one side than on the other. Hence the fungus is usually much nearer the surface on one side of the branch than on the other, even when confined to tissues of the same age. It was found that if the growth of a branch was materially checked, the fungus grew thru the greatest number of annual rings of tissue on the side where these rings were the thinnest. Usually the least deposit of tissues is made on or near the upper surface of the branches. Here also, as a rule, the largest number of injuries occur. Often a very shallow wound extends entirely thru one year's growth of wood. This permits a more rapid advance of the fungus. These tissues are also much less active than on the lower side of the branch where the heaviest deposit of tissues usually occurs. There are actually fewer cell walls to penetrate on the side where the annual rings are the thinnest, since lack of growth consists of a fewer number of cells rather than lack of size of individual cells. It was noted that the proportion of cells produced late in the season and having relatively thick walls was much less in the regions of least growth than on the opposite side of the branch.

In the most susceptible varieties of trees under normal conditions the fungus was found to grow very rapidly in the heartwood. When active tissues were encountered the growth of the fungus was checked, but it still advanced slightly faster

than new tissues were being added on the outside. When the growth of the trees was materially checked the fungus gained very rapidly often killing the tree. This explains why so many Ben Davis trees died during and soon after the severe drouth of 1913. The trees were already infected and were checked by the drouth to such an extent that the fungus was able to invade the tissues very rapidly. Jonathan, Winesap, and many other varieties suffered to a much less extent. In these varieties the fungus was found to progress little if any faster after active tissues were encountered than new tissues were added when the trees were in a normal condition. Hence even when checked by the drouth these varieties still offered a great deal of resistance to its advance.

METHODS OF PREVENTING INFECTION

All accumulated data and observations indicate that methods of control for blister canker must be preventive rather than curative.

The importance of avoiding wounds of all kinds to any parts of the tree has already been emphasized, as well as the necessity of keeping the tree in a moderately vigorous state of growth. The protection of all wounds from infection is of the utmost importance. This may be done by eliminating the source of infection by preventing the formation of spores, or inhibiting them in some manner, and by using disinfectants and adhesive dressings for the wounds.

It was noticed in the laboratory that the stromata absorb water very readily, and that a considerable amount was taken up before the spores were expelled. Copper sulphate and lime sulphur were then used to ascertain if such materials would inhibit spore germination. The different materials in solution were absorbed readily and the beneficial results were found to be twofold. The quantities of spores expelled were noticeably less when either copper sulphate or lime sulphur was used than when water was used. It was also found that a high percentage of the spores did not germinate. The difference was most striking when copper sulphate was employed. When lime sulphur was used about 3 per cent to 5 per cent of the spores germinated and a few produced normal mycelium. When copper sulphate was used 1 per cent to 3 per cent germinated but in no case was normal growth obtained. The hyphae rarely reached the branching stage but after they attained a length of about 1 mm. remained stationary for a time and then disintegrated.

A number of inoculations were made with ascospores on pruning wounds 1 to 2 inches in diameter. These wounds had been covered six months before the inoculations were made. Similar wounds were made and thoroly disinfected three weeks before being inoculated. The results are given in table 16. It was not noticed until too late to remedy the omission that no check was left for the series of disinfectants.

TABLE 16—*Efficiency of various coverings and disinfectants used for pruning wounds in preventing infection**

TREATMENT OF WOUNDS	Total Number of Inoculations	Number of Effective Inoculations	Per Cent Effective
COVER			
Asphaltum (in gasoline)	39	7	17.95
White lead	35	5	14.29
Venetian red	31	13	41.94
Pine tar	16	5	31.36
Coal tar	11	4	36.36
White lead and copper sulphate	35	4	11.43
No cover	51	49	96.08
DISINFECTANT			
Phenol	15	11	73.06
Mercuric chloride 1-500	16	4	25.00
Copper sulphate saturated solution	15	3	20.00
Formalin 20%	12	8	66.67
Lime sulphur 32° Baumé	14	6	42.86
Iron sulphate saturated solution	11	5	45.45

*Covers were applied six months before inoculation, disinfectants three weeks before inoculation.

The evidence indicates that suitable dressings and disinfectants aid very materially in preventing infection. Liquid asphaltum, and white lead and oil appear to be of about equal value. Where either was used there was very little cambium injury and no checking of the wood beneath. In a few cases the covering raised in blisters which later broke and permitted infection. This difficulty was overcome by making a thin application of the paint and later putting on a heavier coat. Both pine tar and coal tar were readily absorbed and much checking of the wood occurred. There was also considerable cambium injury.

Of the disinfectants used copper sulphate proved the most satisfactory. The efficiency of copper sulphate is no doubt due to the fact that the tissues for a short distance beneath the surface of the wound retain the copper for a long time. Tests made over a year after several applications of copper sulphate to the surface of pruning wounds showed the presence of copper in considerable quantities. Practically no injury resulted from the use of copper in this way.

CONCLUSIONS

1 Blister canker is very generally distributed. It occurs in all fruit growing regions of the United States east of the Rocky Mountains and is the most destructive disease of apple trees known.

2 The symptoms of the disease vary with varieties, age of trees, available water and soil nutrients and general weather conditions. Under certain conditions the injury is very similar to that caused by other agencies, such as sun scald, winter injury, collar rot, and the so-called arsenical poisoning.

3 *Nummularia discreta* Tul., is strictly a wound parasite. Infections may occur thru wounds in both roots and branches.

4 Infection may be present in a tree for several seasons before the disease becomes visible on the outside.

5 The disease is disseminated by means of ascospores, conidia, and infected wood.

6 Both conidia and ascospores are produced thruout the growing season if weather conditions are favorable. Conidia are usually produced during the same season in which the canker first appears and on the surfaces of the same stromata for many seasons thereafter. Ascospores are produced one or more seasons after the conidia first appear. One stroma may produce ascospores for several seasons.

7 Ascospores are much more viable than conidia and for this reason offer a better means of disseminating the disease. However, conidia also play an important role in spreading the disease.

8 Infection rarely occurs in rapidly growing tissues, but takes place readily in inactive xylem tissues.

9 The fungus does not destroy the cellular structure but advances thru the pits in the cell walls. The most rapid prog-

ress is made longitudinally thru the tracheae. Radial progress is comparatively slow and is most rapid in the medullary rays.

10 Hyphae are always found closely associated with the characteristic brown discoloration of the wood. The wood cells are often killed several cm. in advance of the invading hyphae.

11 The fungous growth is usually slightly faster below than above the inoculation in parts of the tree above ground. In the roots, the reverse is true.

12 There is a great deal of difference in the susceptibility of different varieties of apple trees to blister canker. Of the common varieties Ben Davis, Gano, and Delicious appear to be the most susceptible while Oldenburg and Wealthy appear to be the most resistant.

13 Susceptibility is greatly influenced by the general vigor of the tree, by the supply of water and soil nutrients, and by the season of the year in which the inoculation occurs. Trees are rendered more susceptible when too little water is available, or when they are under-nourished. The greatest amount of infection is found in trees making less than normal growth. Trees appear to be least susceptible to infection during the period in early spring and summer when they are making the most rapid growth. The addition of fertilizers to the soil not deficient in any element has been of little or no benefit.

14 Both anatomical and physiological factors contribute to cause a variation in resistance of apple trees to blister canker. It is possible that chemical factors may also play an important role.

15 Control measures must be preventive rather than curative. A diseased tree can be cured only by removing all infection. This is obviously impracticable except in a very few cases.

16 The heavy pruning of infected trees aggravates the disease.

17 Both ascospores and conidia may be inhibited by spraying or painting the cankers with either copper sulphate or lime sulphur.

18 Infection may be prevented to a great extent by disinfecting and covering all pruning wounds.

RECOMMENDATIONS

PLANT RESISTANT VARIETIES

One of the greatest factors in controlling blister canker is to avoid planting trees which are known to be very susceptible. It is inadvisable to plant susceptible varieties such as Ben Davis and Gano. These varieties will not prove resistant even under the most favorable conditions and are of poor quality. The Delicious is also a very susceptible variety but is of excellent quality. Varieties such as Jonathan, Winesap, and Stayman will under average conditions live and produce heavily for a long time even after the heartwood has become infected.

AVOID WOUNDS

It is of the greatest importance to avoid making large wounds of any kind. This may be accomplished to some degree by training the trees while young. Small wounds in young trees are not nearly so easily infected as wounds in old trees which expose wood several years old. If a tree is properly pruned and trained while young little pruning will be necessary after the tree reaches bearing age.

PRUNE AT THE PROPER SEASON OF THE YEAR

A little pruning will always be necessary even in well trained trees, but by doing this work at a time when there is the least liability to infection a great deal of the trouble may be avoided. It certainly is not advisable to prune during warm, wet weather. Summer pruning at any time is questionable where wood more than one year old is removed.

DISINFECT AND COVER ALL WOUNDS

Pruning wounds, even if made during the winter, may become infected unless protected by covers. All wounds which expose wood more than one year old should be covered.

Suitable dressings and disinfectants aid very materially in preventing infection. Liquid asphaltum, and white lead and oil appear to be of about equal value. A tendency to blister may be overcome by making an application with the paint quite thin and later putting on a heavier coat. Both pine tar and coal tar are readily absorbed by the wood and allow the wood to check or crack. Considerable cambium injury may also occur.

Copper sulphate has proved the most satisfactory disinfectant owing to the fact that the tissues for a short distance

beneath the surface of the wound retain the copper for a long time.

PREVENT DISSEMINATION OF SPORES

By scraping away and burning all cankered bark from infected trees or by covering all cankered surfaces with a coating of heavy paint or liquid asphaltum a great deal of infection may be avoided. In the first case the spores are destroyed and in the second they are prevented to some extent from escaping. Unless treated in this way all cankers should be thoroly painted or sprayed with copper sulphate at the rate of 1 pound to 2 gallons of water, early in the spring before the dissemination of spores begins. This should also prevent to some extent the formation of new spores.

It would also be well when applying the regular orchard sprays to cover thoroly all parts of the tree. This would offer some protection from canker infection.

When a cankered limb ceases to bear profitably it should be cut off and burned. As soon as a tree becomes so badly diseased that it is no longer profitable it should be removed from the orchard and burned.

New trees may be planted to fill vacancies. There is little danger of their becoming infected thru the roots if one or two-year-old trees are used and the roots are not cut back severely.

(11-3-'17—5M.)

BIBLIOGRAPHY

1 BROOKS, C. Blister Canker. N. H. Agr. Exp. Sta. Bul. 144; 129-130, f. 27. (1909).

2 Blister Canker. N. H. Agr. Exp. Sta. Bul. 157; 23-24, f. 28. (1912).

3 COBB. Agr. Gaz. N. S. Wales, Vol. III, p. 1. (1892).

4 COOK, M. T. and TAUBENHAUS, J. J. The Relation of Parasitic Fungi to the Contents of the Cells of the Host Plants (1. The Toxicity of Tannin). Del. Exp. Sta. Bul. 91. (1911).

5 COOPER, J. R. Spraying Experiments in Nebraska. Exp. Sta. Research Bul. 10. (1917).

6 The Control of Canker in the Orchard. Neb. Hort., Vol. 3. (1913).

7 DUGGAR, B. M. Blister Canker of Apples, Fungous Diseases of Plants; 282-284, 125-126. (1909).

8 ERIKSSON, JACOB. Die Getreideroste 73; 351. (1896).

9 FAUROT, F. M. Apple Tree Canker. Bul. Mo. Fruit Sta. 6:11-12, f. 4. (1903).

10 GLOYER, W. O. Apple Blister Canker and Methods of Treatment. Ohio Exp. Sta. Cir. 125; f. 1-7. (1912).

11 HASSELBRING, H. Canker of Apple Trees. Ill. Exp. Sta. Bul. 70, pl. 1-4. (1902).

12 JONES, L. R., GIDDINGS, N. J., and LUTMAN, B. F. Investigations of Potato Fungus, Phytophthora Infestans, U. S. D. A. Bul. 245. (1912).

13 LAMSON, H. H. Apple Tree Canker. N. H. Agr. Exp. Sta. Bul. 87:130. (1901).

14 NORTON, J. B. Methods Used in Breeding Asparagus for Rust Resistance, U. S. D. A. Bul. 263. (1913).

15 O'NEAL, CLAUDE E. Some Species of Nummularia in Indiana in Proceedings of the Indiana Academy of Science; pp. 235-250. (1914).

16 PADDOCK, W. The New York Apple Tree Canker. N. Y. Agr. Exp. Sta. Bul. 163 (1899) and 185. (1900).

17 SCHWEINITZ. In Trans. of the Am. Philos. Soc., 4:195 No. 1249. (1834).

18 TULASNE. Sel. Fung. Carp. 2:45. (1863).

19 WARD, H. M. The Relation Between Host and Parasite in the Bromes and Their Brown Rust, Puccinia Dispersa (Erikss.) Annals of Botany, Vol. 16; 233-315. (1902).

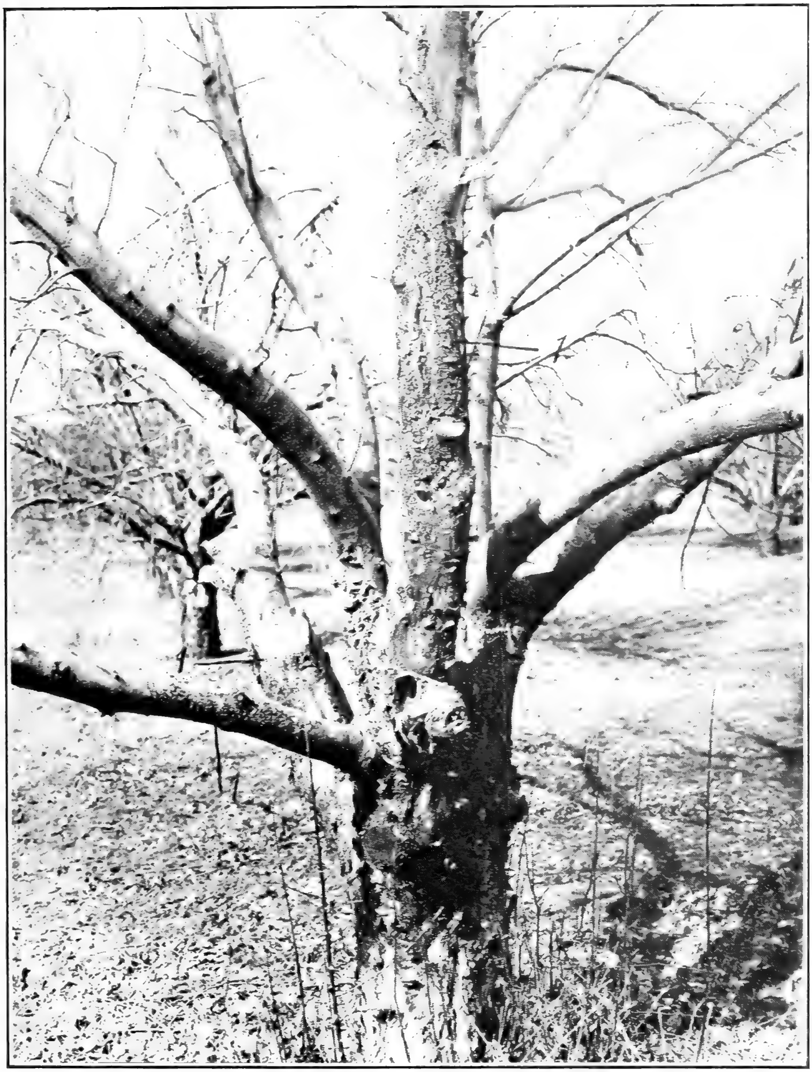
20 Recent Researches on the Parasitism of Fungi. Annals of Botany, Vol. 19; p. 21. (1905).

21 VAUGHAN, R. E. Ann. Mo. Bot. Gar., 1:241, 242. (1914).

DESCRIPTION OF PLATE I

Ben Davis tree showing typical cankers at 1. Such a tree will produce little fruit, and is a menace to the whole orchard.

PLATE I



DESCRIPTION OF PLATE II

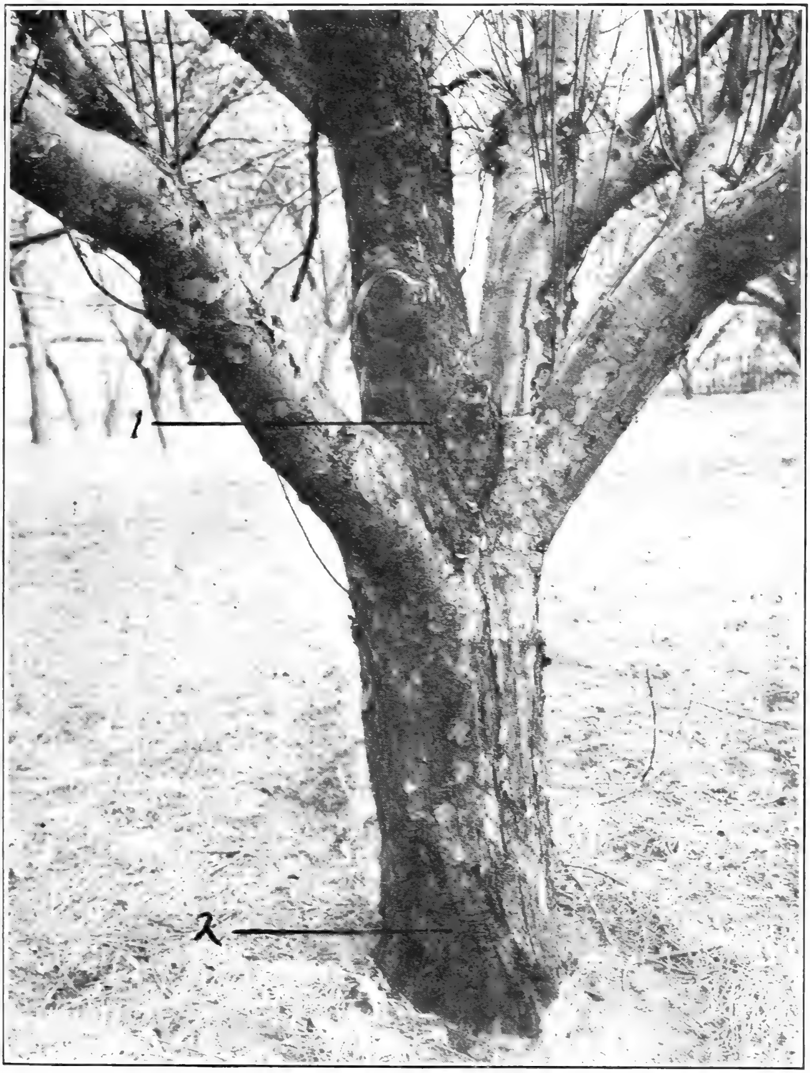
Ben Davis tree apparently healthy when examined May 1, 1917. The photograph taken July 1 shows that practically no growth was made after May 1. By the middle of September characteristic stromata had appeared on several of the branches.

PLATE II

DESCRIPTION OF PLATE III

Grimes Golden tree with large canker on a main branch at 1, and a large canker extending more than half way around the trunk at 2. Cankers like the one at 2 are very common on this variety.

PLATE III



DESCRIPTION OF PLATE IV

A. Canker measuring 1½ x 7 inches which developed within a single week. Stromata appeared on the surface during the same season.

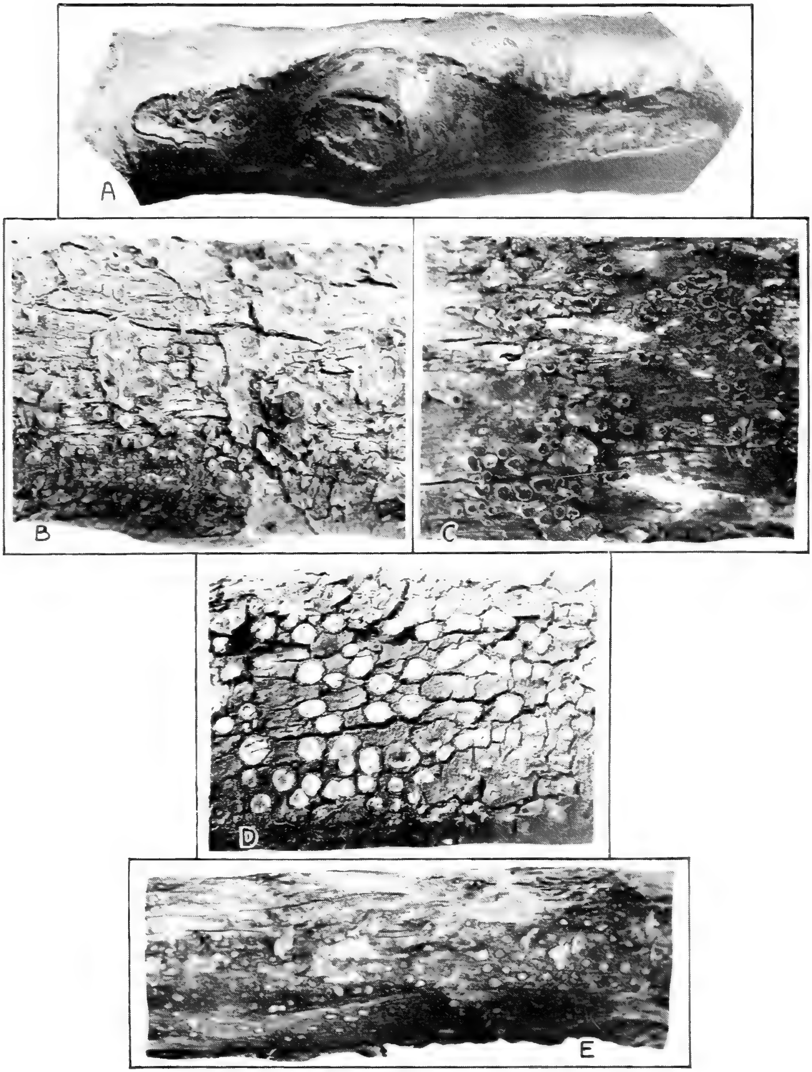
B. Portion of an older canker. No ascospores have yet been produced.

C. Portion of a canker more than four years old. Much of the bark has fallen away but the stromata are still firmly attached. The black color is due to the presence of ascospores which have recently matured and been forced to the surface.

D. Portion of an old canker with the stromata covered with conidia.

E. Portion of a cankered limb from which the diseased bark has been cut away revealing the light colored spots with black edges where the stromata had been attached.

PLATE IV



DESCRIPTION OF PLATE V

A. Camera lucida drawing of germinating conidia.

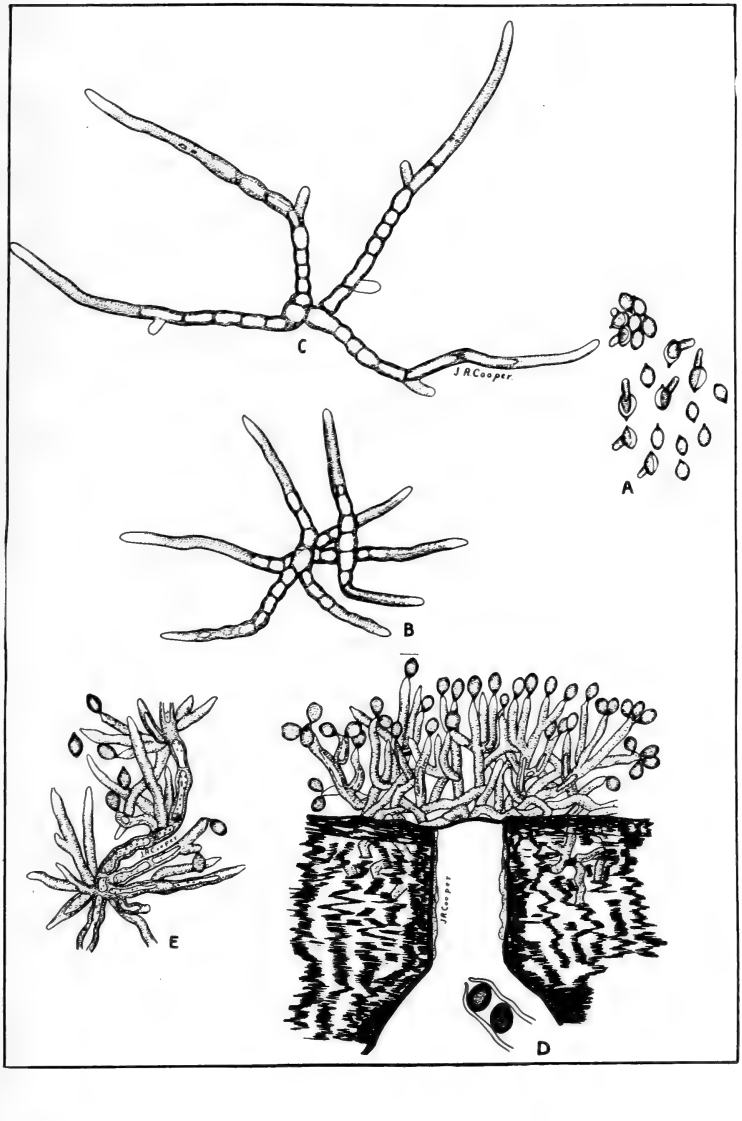
B. Camera lucida drawing 36 hours after germination of conidia.

C. Camera lucida drawing 60 hours after germination of conidia.

D. Camera lucida drawing of section of stroma producing ascospores within, and conidia on the surface.

E. Camera lucida drawing of section of mycelium grown in culture, producing conidia.

PLATE V

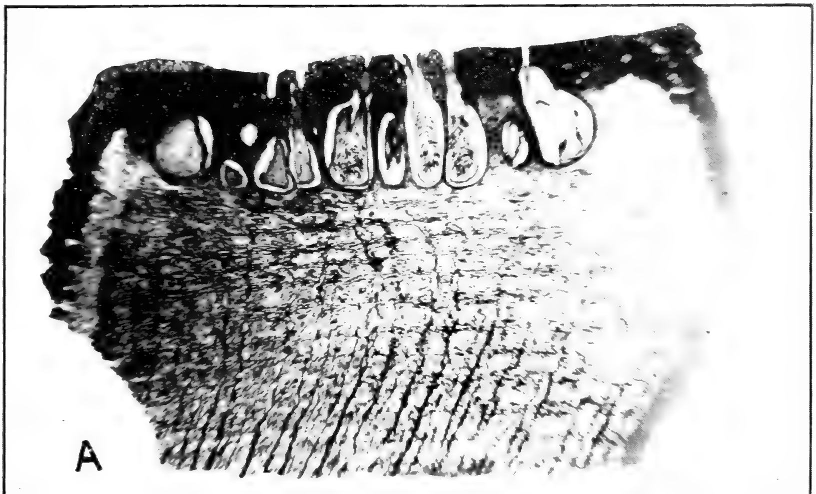


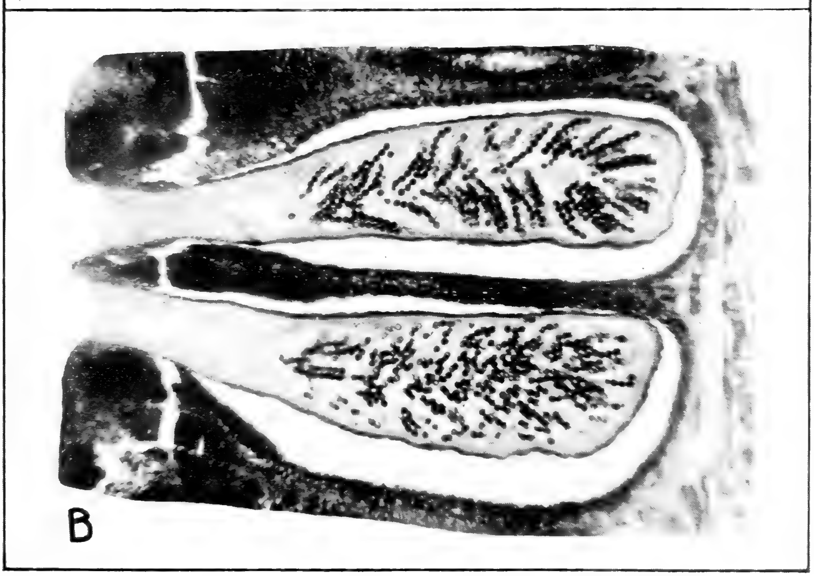
DESCRIPTION OF PLATE VI

A. Microphotograph of cross section of a stroma. The spores had been expelled from several of the perithecia.

B. Microphotograph (much enlarged) of two of the perithecia shown in A. Asci and ascospores of all degrees of maturity are shown. The light colored spores are still immature.

PLATE VI





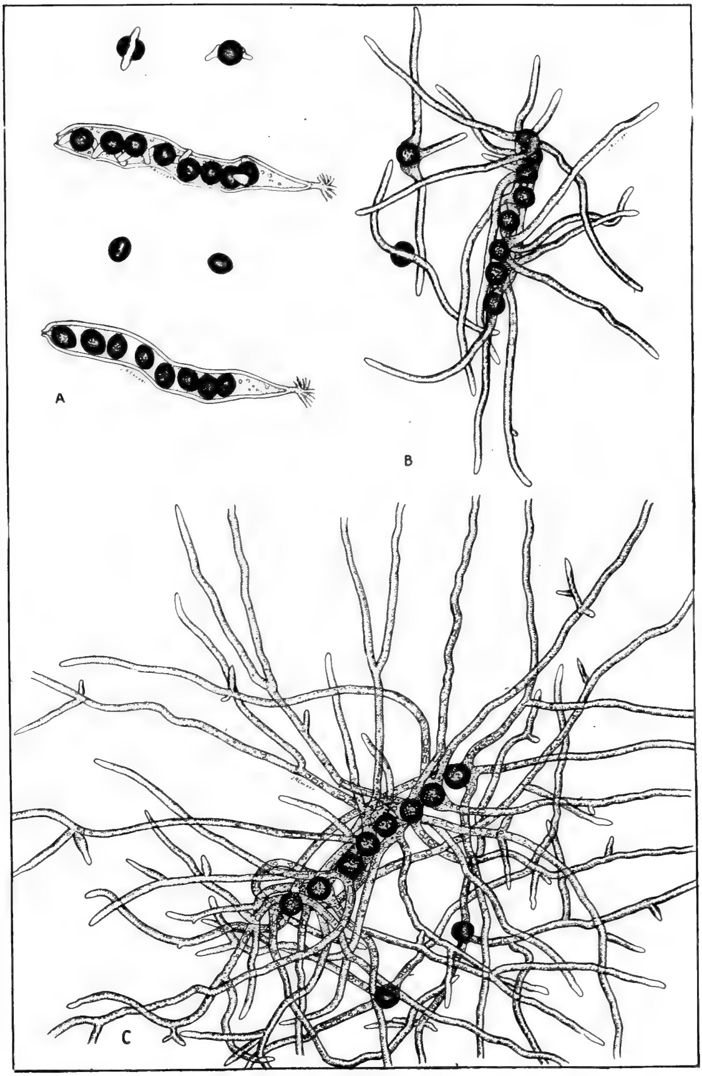
DESCRIPTION OF PLATE VII

A. Camera lucida drawing of ascus and ascospores, when first removed from the stroma and the same after germination of the ascospores.

B. Camera lucida drawing of ascospores 36 hours after germination.

C. Camera lucida drawing of ascospores 60 hours after germination.

PLATE VII



DESCRIPTION OF PLATE VIII

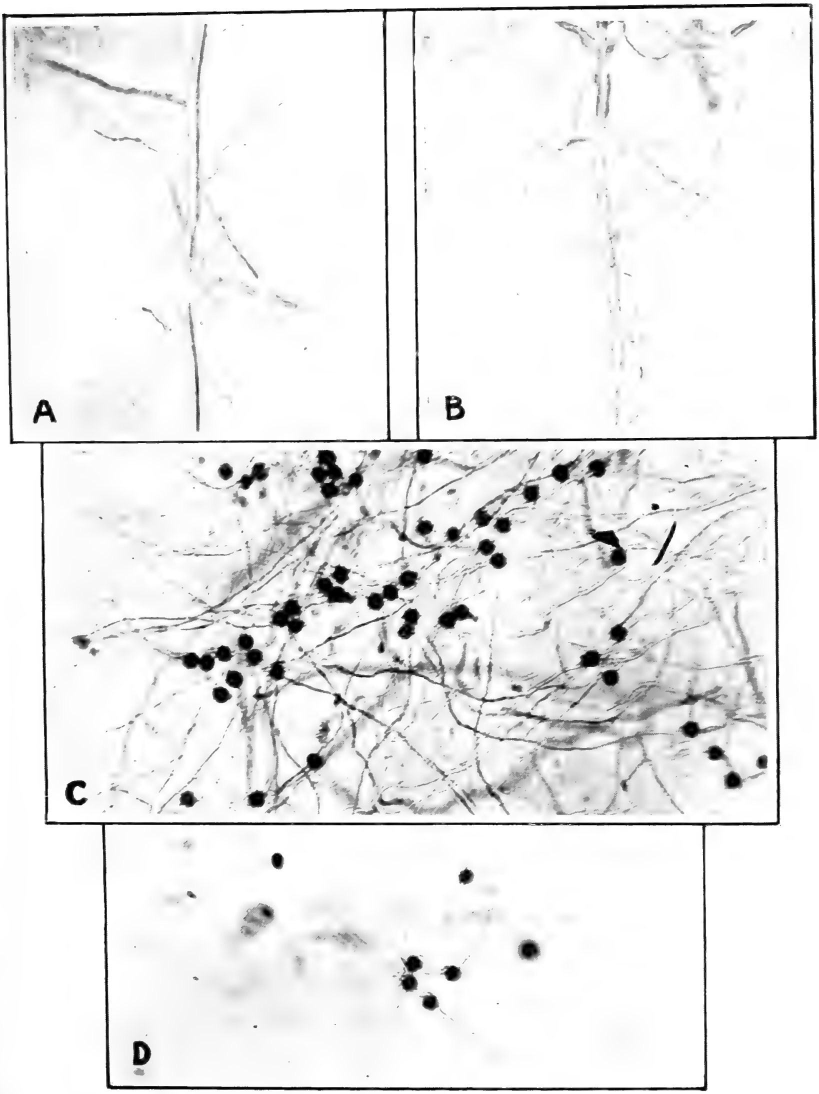
A. Microphotograph of a single hypha in pure culture showing the manner of branching.

B. Microphotograph of a hypha several days older than the one shown at A.

C. Microphotograph of ascospores 60 hours after germination.

D. Microphotograph of germinating ascospores.

PLATE VIII



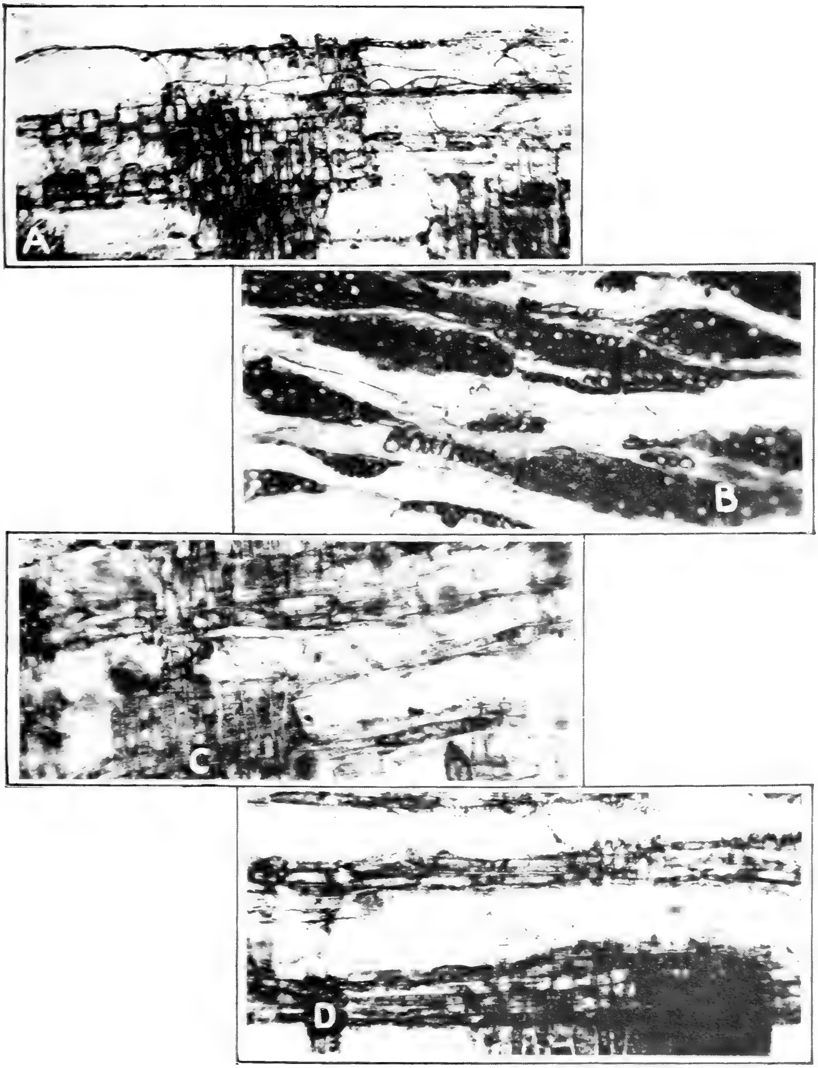
DESCRIPTION OF PLATE IX

A, B, C, and D. Microphotographs of longitudinal sections of apple wood showing invading hyphae.

In A, the hyphae are shown in the medullary ray cells as well as in the tracheae.

In C, the hyphae are shown passing thru the pitted walls of two adjoining tracheae.

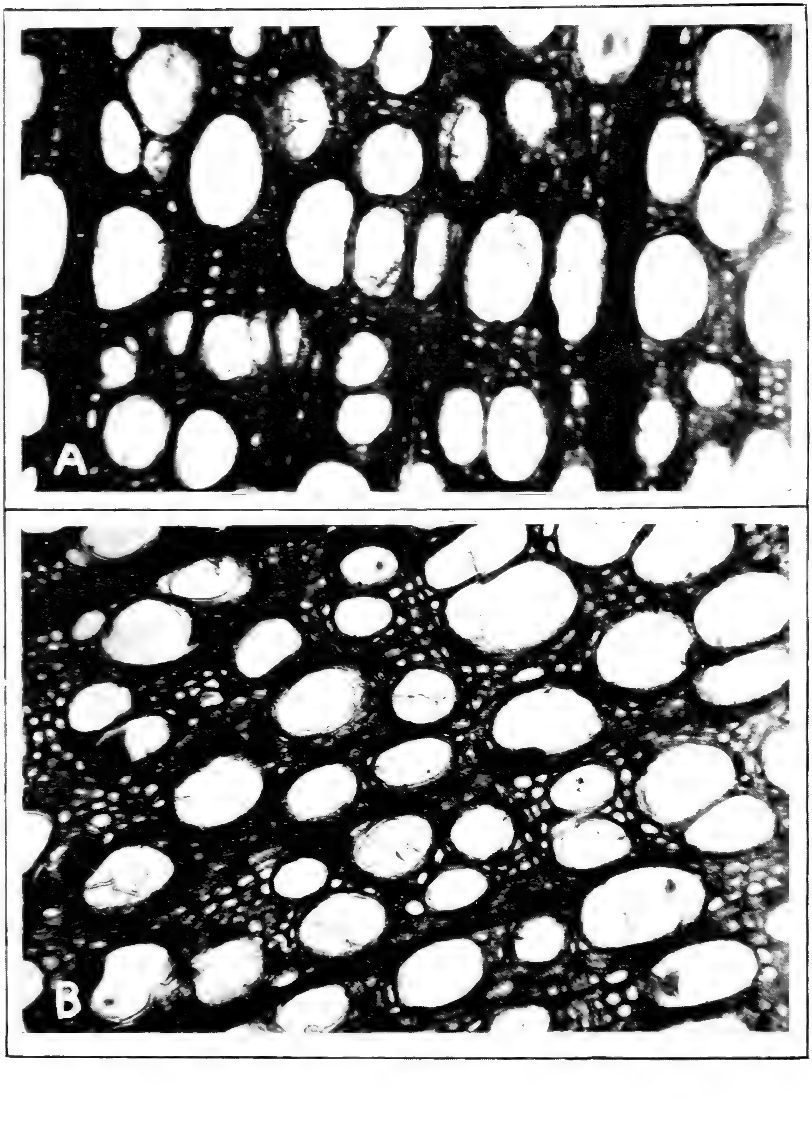
PLATE IX



DESCRIPTION OF PLATE X

A and B. Microphotographs of cross sections of apple wood showing invading hyphae.

PLATE X

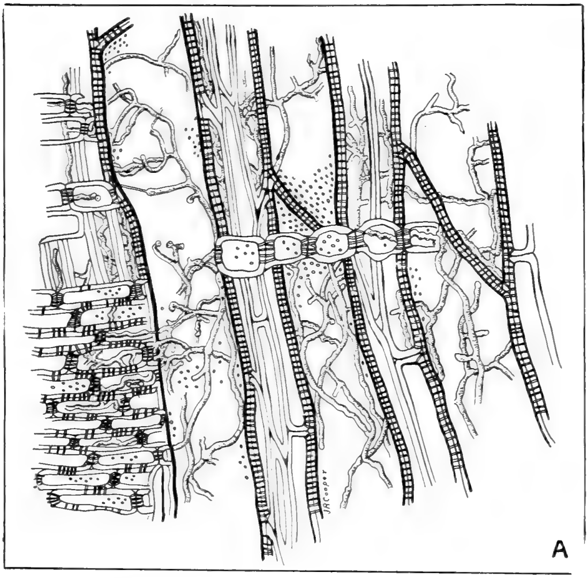


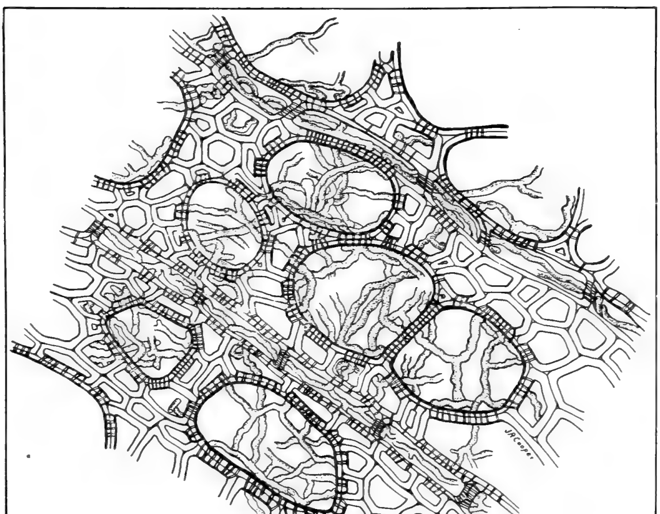
DESCRIPTION OF PLATE XI

A. Camera lucida drawing of longitudinal section of apple wood showing invading hyphae. The wood cells are not broken down but the hyphae pass from one to the other thru the pitted walls.

B. Camera lucida drawing of cross section of apple wood and invading hyphae.

PLATE XI





DESCRIPTION OF PLATE XII

Arrangement of trees which were supplied with nutrient solutions, showing where water supply was controlled.

Trees in three rows at the right and those in the foreground on the left are growing in nutrient solution. The jars were buried in soil to prevent injury to roots by heat. Solutions supplied thru small jars at 1.

Trees in the left background grown in covered half-barrels. Water was added thru holes in the covers, in which corks were fitted.

PLATE XII

DESCRIPTION OF PLATE XIII

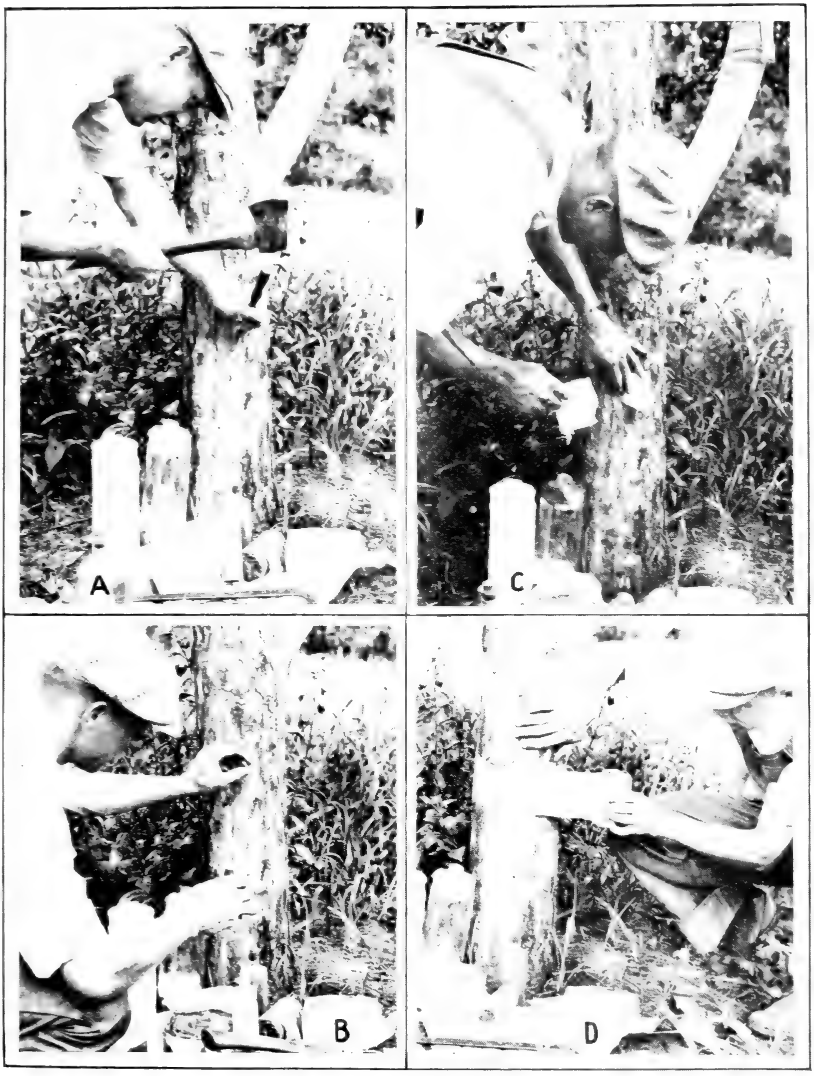
A. Making cut in which to insert inoculum. In this instance a half-inch wood chisel was used.

B. Inserting inoculum in wound.

C. Covering inoculation with sterilized cotton, and covering this in turn with a square of paraffined cloth.

D. Putting on the protective covering of cloth which has been saturated with grafting wax. In the upper right-hand corner of C is a finished inoculation showing wrapping and zinc label.

PLATE XIII



DESCRIPTION OF PLATE XIV

Cross sections of trunk and branches of Ben Davis tree, which was starved by having a portion of the root system removed, and inoculated.

The tree cut off just above the ground. Cross sections 2 inches thick were removed at approximately 16-inch intervals. These blocks were planed and photographed. The crown and roots were also dug up and examined.

A. Crown of tree. As shown in the photograph little of the infection extended into the roots. One root, however, which was close to the surface of the ground was infected for several feet. Infection emerged below the crown of the tree.

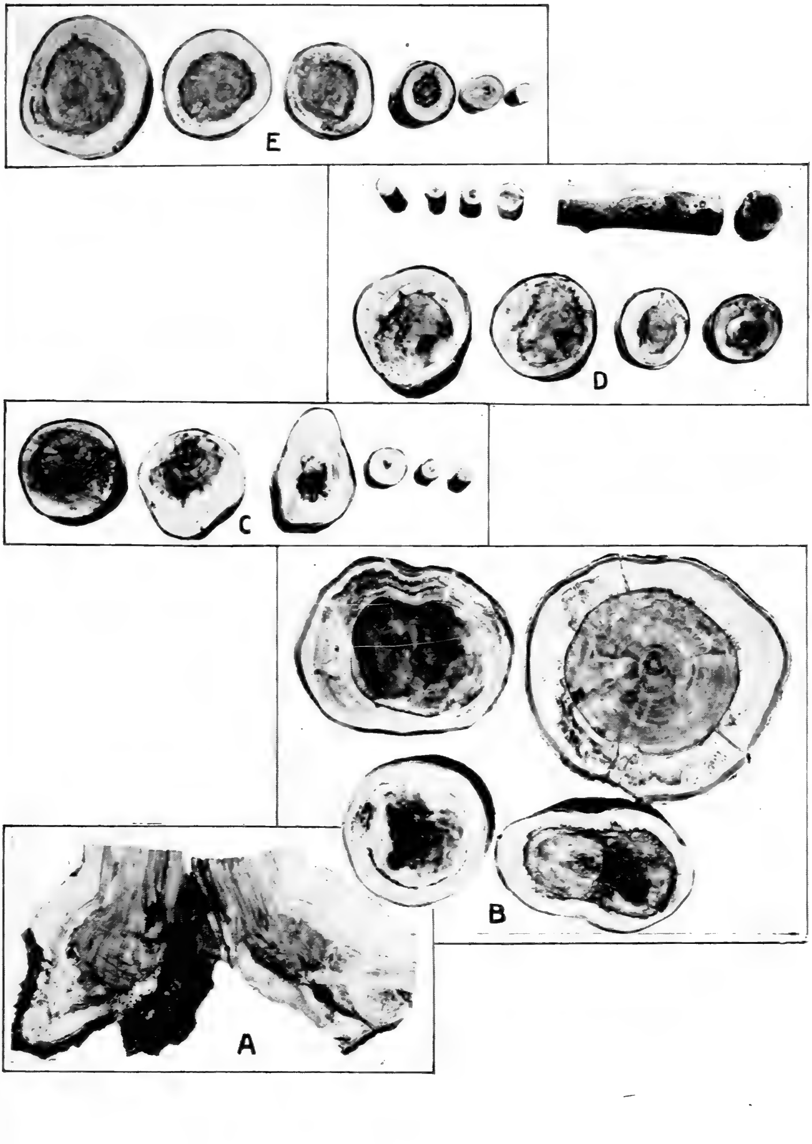
B. Two sections of trunk and two sections of main limb.

C and D. Branches attached to the lower right-hand block in B.

E. Branch attached to opposite lower left-hand block in B.

Infection was close to the surface over the entire tree. One characteristic canker was formed on branch D.

PLATE XIV



DESCRIPTION OF PLATE XV

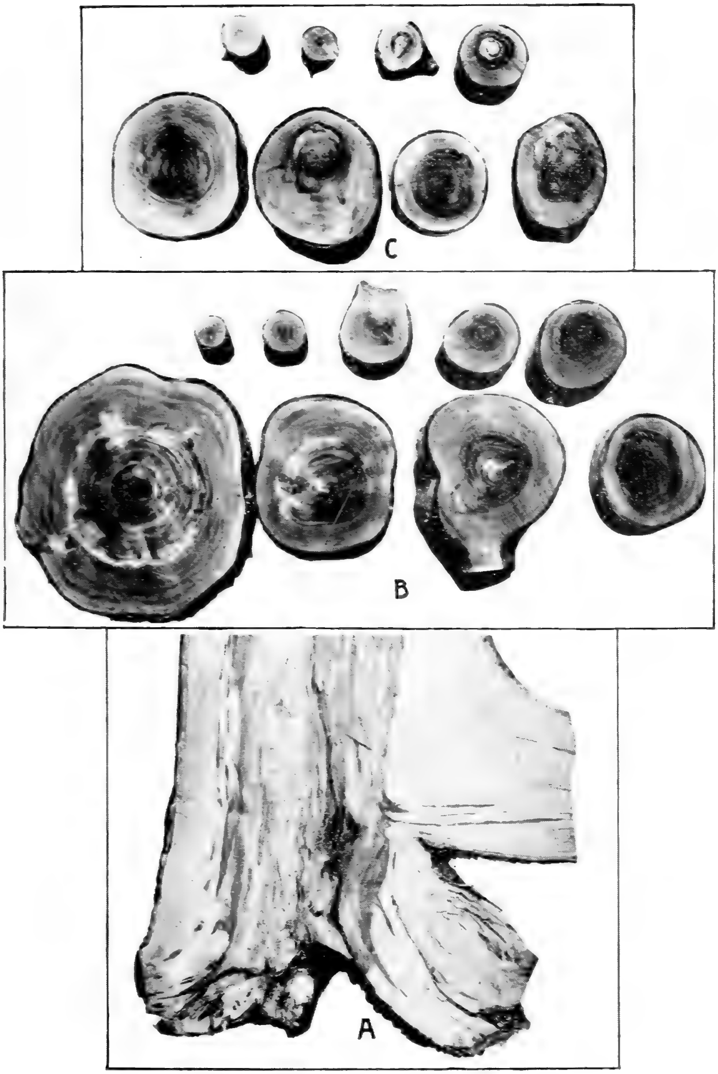
Cross sections of trunk and branches of Jonathan tree treated as described in plate XIV for Ben Davis.

A. Crown of tree. As in the case of the starved Ben Davis, the canker infection emerged at the bottom. However, none of the roots were infected.

B. One section of trunk and eight sections of main limb.

C. Eight sections of main limb attached opposite limb shown in B. The last section was not infected. Infection did not extend as far longitudinally or laterally as in the case of the Ben Davis trees treated in the same way.

PLATE XV



DESCRIPTION OF PLATE XVI

Ben Davis tree inoculated but not starved.

A. Crown of tree. The infection here was slight but emerged thru a crack below.

B. One section of trunk and eight sections of main limb.

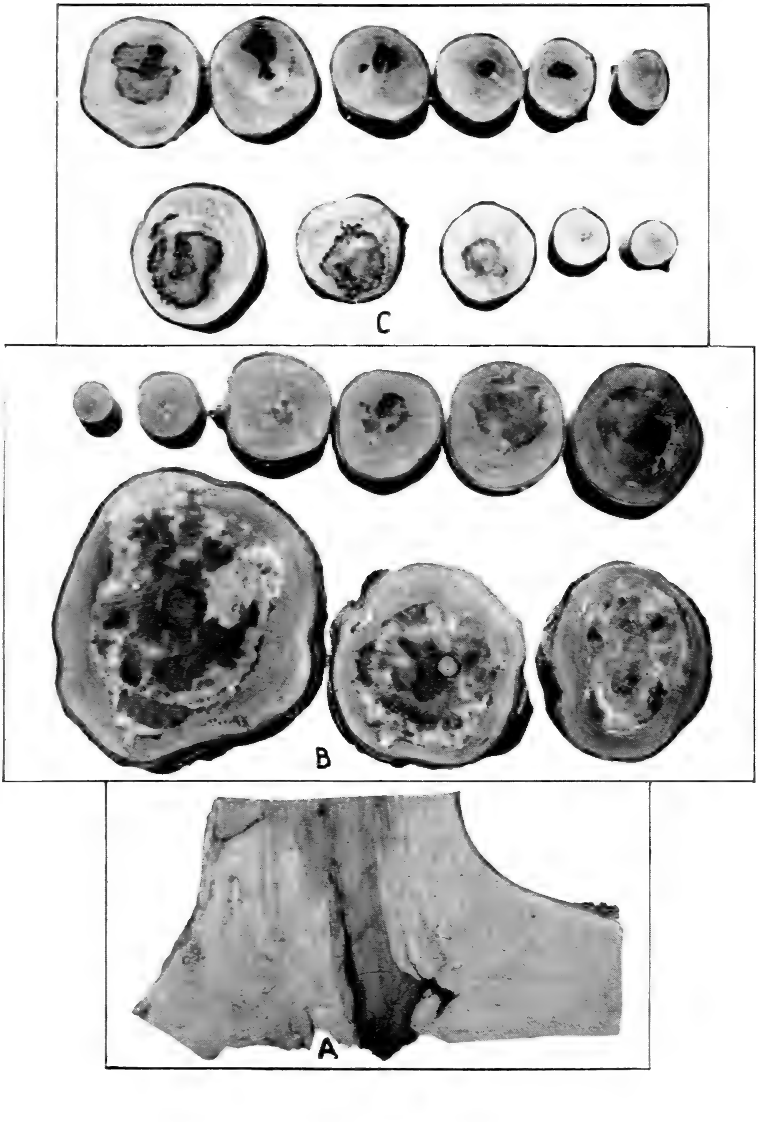
C. Lower series, five sections of limb attached just above section 3 in B. Upper series six sections of limb attached opposite section 2 in B.

The last section in all cases was free from infection.

The amount of infection was considerably less both longitudinally and laterally than in the case of the starved Ben Davis.

No cankers were formed.

PLATE XVI



DESCRIPTION OF PLATE XVII

Jonathan tree inoculated but not starved.

A. Crown of tree. No infection extended below the crown.

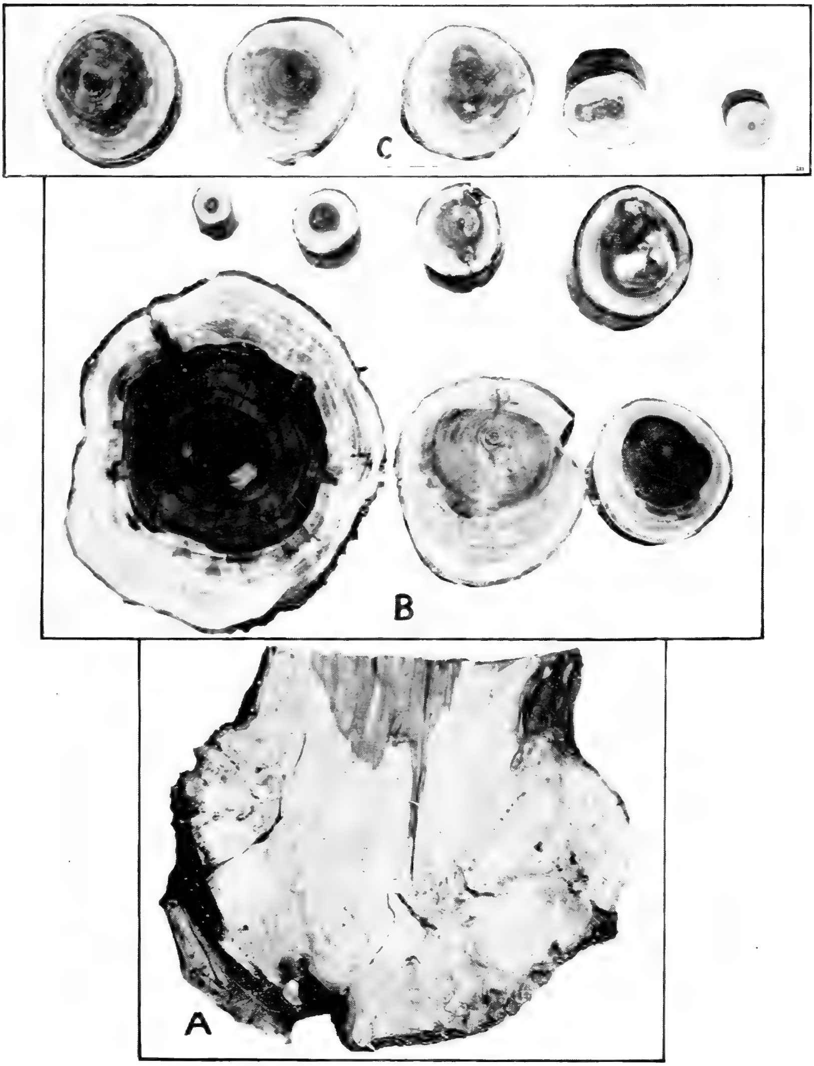
B. One section of trunk and six sections of one main limb.

C. Five sections of main limb attached opposite limb in B.

The amount of infection was less than in the case of the unstarved Ben Davis or the starved Jonathan.

No cankers were formed.

PLATE XVII



DESCRIPTION OF PLATE XVIII

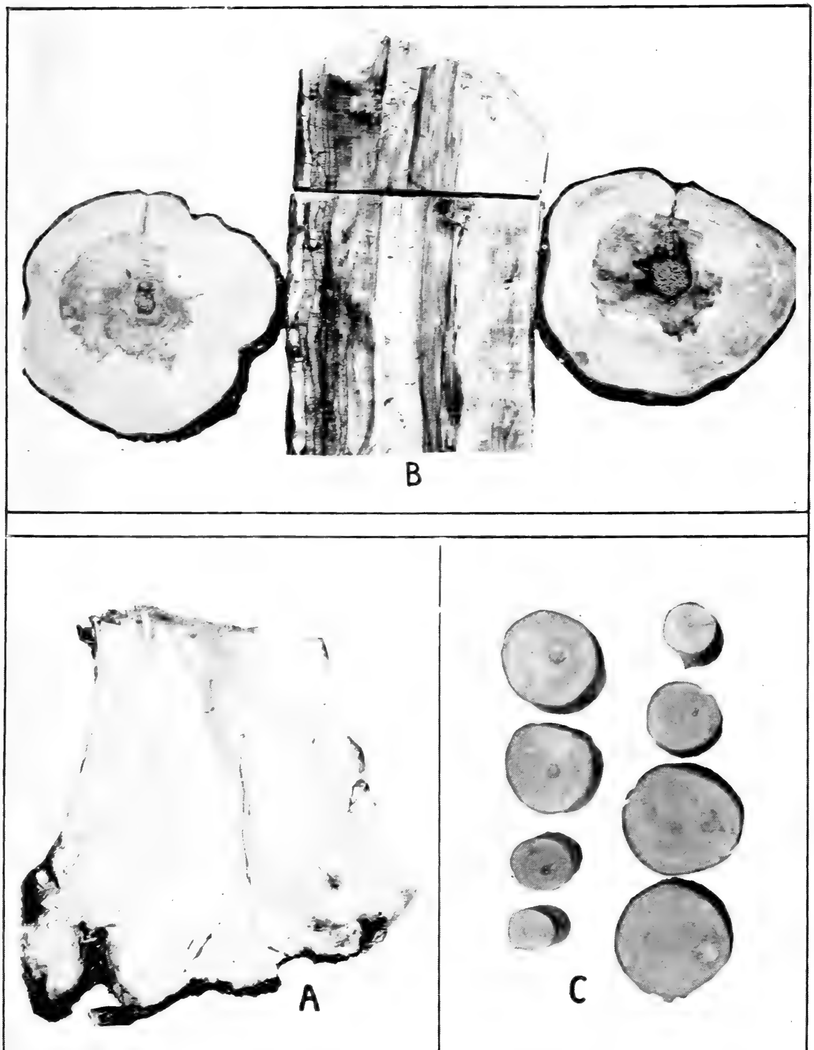
Jonathan tree infected by wild inoculation thru frost crack in trunk.

A. Crown of tree. Infection did not extend into the crown.

B. Two cross sections of trunk, one longitudinal section between the two cross sections and one between lower cross section and crown. Longitudinal sections show the depth of the frost crack and accompanying infection.

C. Sections of two main branches showing a slight amount of infection.

PLATE XVIII



DESCRIPTION OF PLATE XIX

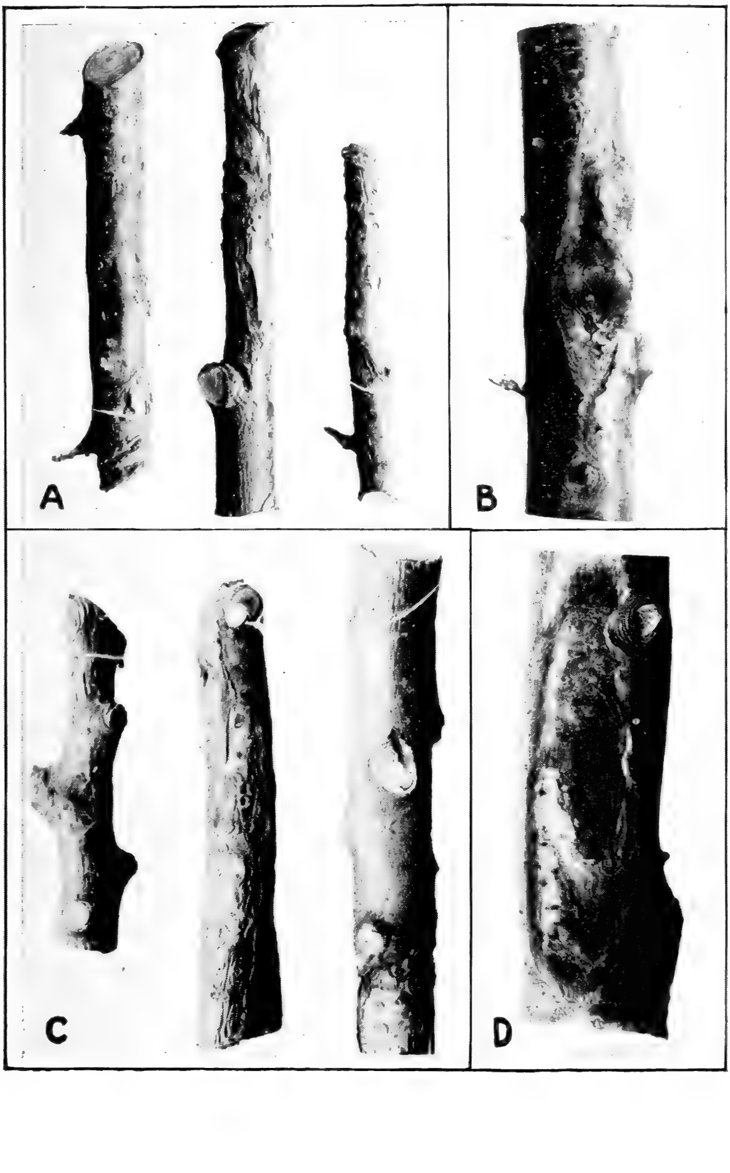
A. Cankers resulting from pure culture inoculations on stubs.

B. Canker resulting from pure culture inoculation in xylem.

C. Cankers resulting from ascospore inoculation on stubs.

D. Canker resulting from ascospore inoculation in heartwood.

PLATE XIX



DESCRIPTION OF PLATE XX

One of the older Nebraska orchards. On the left a Jonathan block. All the trees are still bearing heavily. On the right a Ben Davis block planted at the same time and cared for in the same way.

The picture tells its own story.

PLATE XX

DESCRIPTION OF PLATE XXI

Another Nebraska orchard. The trees are all Ben Davis. Nearly all are dead. All will be dead in another year or two.

PLATE XXI

DESCRIPTION OF PLATE XXII

Injuries which permit ready infection.

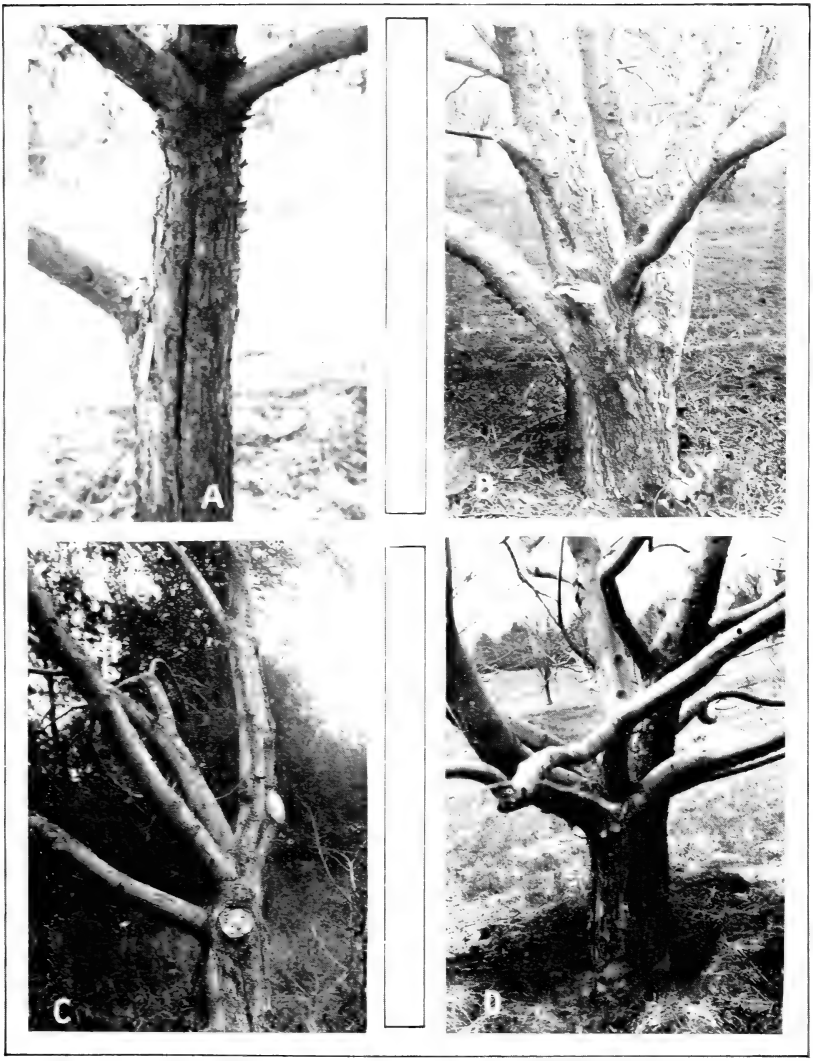
A. Tree split by frost.

B. A poor job of pruning.

C. Combination of sun scald and borer injury.

D. Tree injured at the base by mice.

PLATE XXII

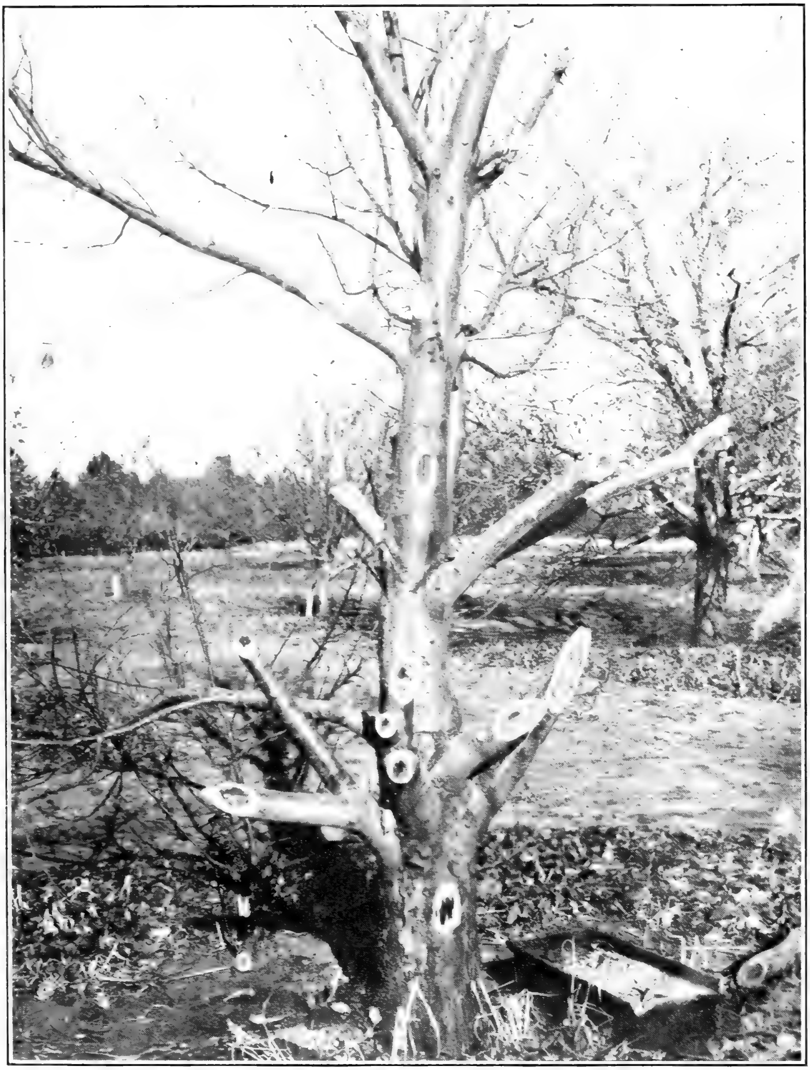


DESCRIPTION OF PLATE XXIII

Ben Davis tree infected with canker. All the wood more than two years old and in many places all but the one-year-old wood was infected.

This shows the futility of attempting to control canker by cutting it out.

PLATE XXIII



DESCRIPTION OF PLATE XXIV

Methods of treating canker.

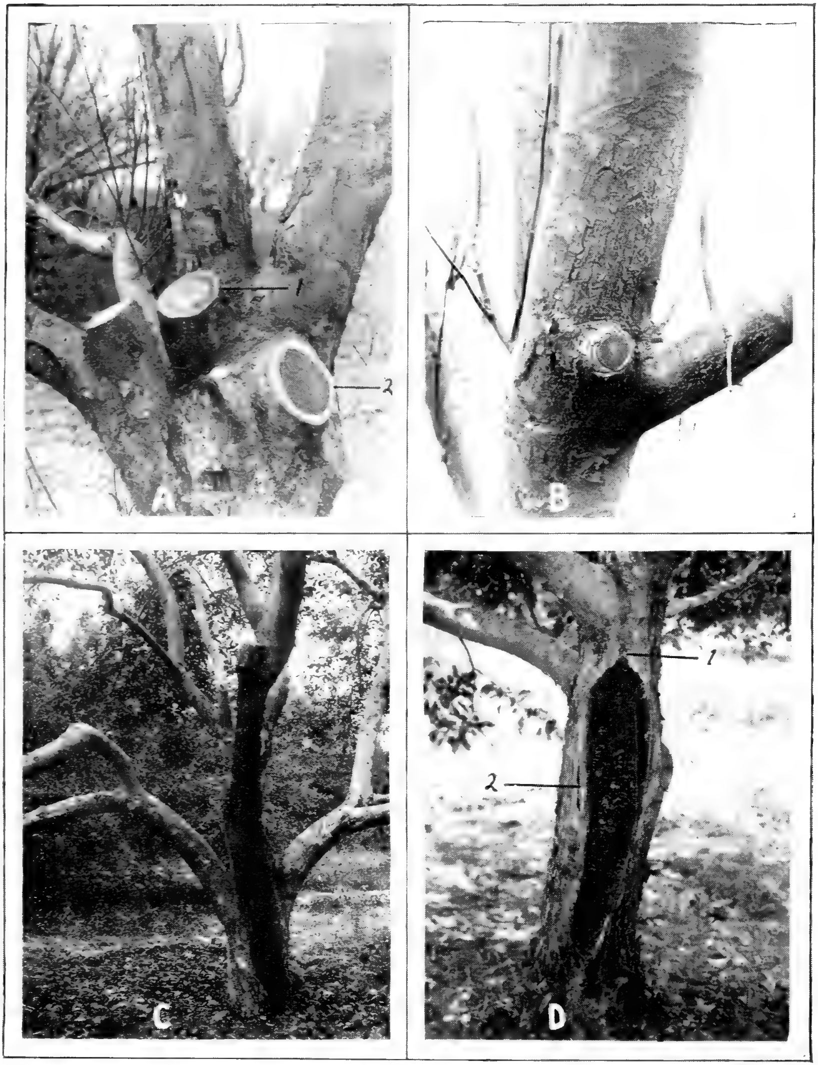
A. Cankered limbs were removed but, as shown at points 1 and 2, all the wood except that formed during the last year was infected. The next year cankers appeared on the remaining limbs.

B. Cankered limb removed but the canker is spreading up and down the trunk.

C. Nearly half of the bark and a portion of the wood was removed for a distance of nearly six feet, and the wound covered. This is a useless expenditure of time and money.

D. A cankered limb was removed and an attempt made to remove all infected wood. It was found impossible to remove all of the diseased wood. Two years after treating canker appeared at 1 and 2.

PLATE XXIV



RESEARCH BULLETIN NO. 13

THE UNIVERSITY OF NEBRASKA

BULLETIN

OF THE

AGRICULTURAL EXPERIMENT STATION

OF

NEBRASKA

STUDIES CONCERNING THE ELIMINATION OF EXPERIMENTAL ERROR IN COMPARATIVE CROP TESTS

By T. A. Kiesselbach

Accepted for Publication December, 1917

Distributed June 15, 1918

LINCOLN, NEBRASKA, U. S. A.

AGRICULTURAL EXPERIMENT STATION OF NEBRASKA

CONTENTS

SUMMARY

1. In determining the effect of competition between single-row test plats as a source of experimental error in crop yield tests, the relative yields of two crops planted in blocks containing several rows have been regarded as the true relative values for the crops tested. In ascertaining some of these true values, the outer rows of the plats have been discarded in order to eliminate almost entirely plat competition. Plats were sufficiently replicated to secure quite reliable relative yields for the conditions under which they were grown.

In plat competition tests in 1913 with two rates of planting Turkey Red wheat, the thin rate yielded 68 per cent as much as the thick rate when grown in single alternating rows, while in five-row blocks the thin rate yielded 90 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 24.4 per cent too low. In a similar test in 1914 the thin rate yielded relatively 56.8 per cent too low.

2. In 1913, competition between alternating rows of two rates of planting with Kherson oats caused the thin rate to yield relatively 20 per cent too low. In 1914, similar single-row competition caused the thin rate to yield relatively 34.3 per cent too low.

3. In 1914, competition between alternating single-row plats of Turkey Red wheat sown at two rates reduced the relative number of stools per plant approximately 37 per cent for the thin rate. There was a similar reduction of 20 per cent for Kherson oats, due to plat competition.

4. The relative competitive effect of varieties varies in different years, due to difference in adaptation to the seasonal conditions.

In 1913, competition with Turkey Red winter wheat in single rows caused Big Frame winter wheat to yield relatively 10.3 per cent too high. In similar competition in 1914 Big Frame yielded relatively 12.4 per cent too low.

In 1913 there was practically no competitive effect between alternating rows of Turkey Red and Nebraska No. 28 winter wheat varieties. This was due to abnormal climatic conditions. However, in 1914 under rather normal conditions competition between single-row plats caused the Nebraska No. 28 to yield relatively 25.9 per cent too low.

5. In 1913 in alternating single-row test plats of Burt and Kherson oats, the Burt yielded relatively 16 per cent too high, while in 1914 the yield was relatively 37.6 per cent too high, due to plat competition.

In 1913, competition with Kherson oats in alternating one-row plats caused Swedish Select oats to yield relatively 7 per cent too high, while in 1914 its yield was relatively 4.3 per cent too low.

6. When large and small seeds of wheat were planted in competition in the same row, the small seed, as a result of competition, yielded relatively 15 per cent too little grain, 20 per cent too little straw, and made 18 per cent too small total yield.

Similar competition was found between varieties of wheat planted in the same row.

7. In a single-row test of 80 strains of Turkey Red wheat grown in the same order each of four years, there are evidences of plat competition between strains. As an average for four years, the poorest strain, No. 75, grew between strains No. 74 and No. 76, ranking one and five. A special test of these three strains in 1915 and 1916 disclosed that strains No. 74 and No. 76 were favored 20 and 15 per cent respectively thru competition with a less vigorous strain.

8. In a rate-of-planting test with Nebraska White Prize corn,—in which two rates of planting, namely two and four plants per hill, were compared in alternating single row plats, —the thin rate yielded relatively 29.3 per cent too low in 1914 because of plat competition. In 1915 the thin rate yielded 9 per cent too low because of plat competition. In 1916 such competition caused the thin rate to yield relatively 16.1 per cent too low.

9. A large, medium, and small variety of corn were grown in plat competition studies during 1912 and 1914. These varieties were Hogue's Yellow Dent, University No. 3, and Pride of the North, respectively. In 1912, Pride of the North yielded 85 per cent as much as Hogue's Yellow Dent in alternating three-row plats, while it yielded 66 per cent as much in alternating single rows. When compared in the same hill by the intra-hill method, the Pride of the North yielded only 47 per cent as much as Hogue's Yellow Dent. Due to competition, the Pride of the North yielded relatively 44.7 per cent too low when compared in the same hill, and 22 per cent too low in alternating one-row plats.

10. In 1914, due to plat competition, Pride of the North corn yielded relatively 51 per cent too low when compared with Hogue's Yellow Dent in the same hill, while in alternating single-row plats it yielded relatively 28.3 per cent too low.

In a comparison of University No. 3 with Hogue's Yellow Dent, the University No. 3 yielded relatively eight per cent too low in single-row plats, and within the hill it yielded relatively one per cent too high. The lack of competition within the hill in this case may have been due to there being only two plants of a rather similar type in a hill. When all three varieties were compared in the same hill, the relative yields for Hogue's Yellow Dent, University No. 3, and Pride of the North were respectively 100, 96, and 28, as compared with 100, 98, and 53 in the center row of three-row plats and 100, 98, and 38 in single rows.

11. In 1916, inbred Hogue's Yellow Dent corn which had been greatly reduced in vigor by five years of self-fertilization was compared with the more vigorous first generation hybrid of two such pure lines, in blocks, rows, and hills. Because of competition with the larger plants in the same hill, the inbred corn yielded relatively 44 per cent too low, while in alternating single rows, it yielded relatively 16 per cent too low.

12. Studies with oats, wheat, and corn suggest that the yield of the border rows of narrow, adjacent test plats may be materially affected by plat competition.

13. When surrounded by corn hills having a full stand of three plants, two-plant hills and three-plant hills respectively yielded 10.5 per cent and 35 per cent more than a one-plant hill in 1914. In a similar test in 1917, two-plant hills and three-plant hills respectively yielded 67 and 102 per cent more than a one-plant hill.

14. The average grain yield of a three-plant corn hill surrounded by a full normal stand of three plants per hill was 465.8 grams in 1914. This yield per hill was increased 2.7, 5.3, 13.1, and 43.1 per cent by the presence, respectively, of (1) one adjacent hill with two plants, (2) one adjacent hill with one plant, (3) one adjacent blank hill, and (4) two adjacent blank hills. In 1917 corresponding adjacent imperfect hills increased the grain yield of three-plant hills, otherwise surrounded by a full stand, respectively 2, 9, 15, and 25 per cent.

15. Regarding three plants per hill as a perfect stand, the reduction in yield of corn was not proportional to a reduction in stand. With single-row plats, stands averaging 92.8, 87.2, 82.7, 77.8, 73.1, 66.6, and 43.0 per cent yielded respectively 85.5, 88.1, 83.5, 82.2, 77.9, 74.8, and 56.7 bushels per acre.

16. Satisfactory yield correction for corn based upon per cent of stand cannot be made, because the effect upon yield depends upon the distribution of the missing plants and because the effect upon yield is not proportional to the per cent stand. Comparable yield tests of similar varieties or strains of corn may be secured by basing the yield upon a counted number of hills containing a uniform number of plants and surrounded by a full stand.

17. Corn varieties or types differing markedly in growth characteristics should be tested at several rates of planting, because the optimum rate for one is not necessarily that for another. Thus, as an average for two years, Pride of the North and Calico produced their maximum yield when grown at the rate of five plants per hill, while Mammonth White Pearl yielded best at the three-rate. In 1914, Pride of the North yielded most at the five-rate, University No. 3 did equally well at the two and three-rate, while Hogue's Yellow Dent produced best at the two-rate.

18. The removal of suckers affects the yield of varieties differently, and for this reason suckers should for no reason be removed in comparative variety tests.

19. In comparative yield tests where it is not convenient to harvest and thresh the entire plats, fairly reliable results may be obtained by harvesting and averaging a large number of systematically distributed small fractional areas or quadrates from each plat. The necessary number of quadrates to be representative will vary with the size of the plats.

Twenty 32-inch quadrates harvested from thirtieth-acre wheat plats gave fairly reliable results. Less than 20 proved likely to be unrepresentative of the plats. Very satisfactory results were obtained by having 40 quadrates represent one-fifteenth acre of wheat.

20. Two hundred and seven thirtieth-acre plats were grown to a uniform crop of Kherson oats for the purpose of studying various phases of experimental error. Calculations have been made from them to show: (1) The use and

effectiveness of check plats for reducing test plats to comparable yields; (2) the reduction of error by the replication of plats; (3) the relative reliability of plats of various sizes and shapes; and (4) the significance of the "probable error" as a measure of confidence which may be placed in mean results.

When the odd and even numbered plats of these 207 are regarded as check plats and test plats respectively and the grain yield of each test plat is corrected by the mean of the two adjacent check plats, the coefficient of variability for the actual yields of these test plats is reduced from 7.85 per cent for the actual yields to 7.01 per cent for the corrected yields. Assuming every third plat to be a check, and correcting the intervening plats by the one adjacent check plat, the coefficient of variability was reduced from 7.79 per cent to 7.35 per cent.

With every third plat regarded as a check plat, and the intervening plats corrected progressively by the two nearest checks, the coefficient of variability is reduced from 7.87 to 6.57 per cent. Thus it is seen that none of the three methods of check plat correction have been very effective.

The yield of systematically distributed check plats cannot be regarded as a reliable measure for correcting and establishing correct theoretical or normal yields for the intervening plats.

21. Systematic replication of plats is the most effective and satisfactory means for reducing error caused by soil or other environmental variations. When 200 thirtieth-acre plats were planted to a uniform crop of Kherson oats, the coefficients of variability for the grain yields of single plats and for the mean yields of two, four, and eight plats were 6.30, 4.59, 2.91, and 2.13 per cent respectively. The extreme variation between yields was also reduced from 20.7 bushels for single plats to 7.5 bushels for the means of eight plats.

Reduction of error by averaging adjacent plats (which is equivalent to increasing the size of the plat) was far less effective than systematic replication. The coefficients of variability for single plats and for the mean yields of two, four and eight adjacent plats were 6.30, 5.46, 5.28, and 4.78 per cent.

Variation between long, narrow plats was less marked than for short, wide plats of the same area. The coefficient of variability for tenth-acre oats plats 48 rods by 5.50 feet was

3.84 per cent as compared with 5.18 per cent for plats 16 rods by 16.5 feet.

22. Two hundred uniformly planted thirtieth-acre Kherson oats plats were arranged in 50 groups of four adjacent plats each, and also in 50 groups of four systematically distributed plats. For both methods of grouping, the "probable error" has been calculated for the mean yield of each group of four plats. The results indicate that a small probable error cannot be regarded as sufficient reason for confidence in the reliability of data. Because of chance groupings of either large or small variations where relatively small numbers are used, a mean may be either more or less accurate than an application of the probable error would indicate.

23. In four comparative rate-planting yield tests with small grains in alternating single-row plats the probable error was less than 2 per cent in all cases, and yet there existed an average actual error of 34 per cent in relative yields due to plat competition. Similar results are indicated for variety tests with small grains.

24. An application of the probable error to tests made in 1916 concerning the relative water requirement for grain production of Hogue's Yellow Dent corn and Turkey Red winter wheat may result in greatly misplaced confidence. We may be confident from one test that Hogue's Yellow Dent corn uses considerably less water per pound of grain than does Turkey Red wheat, and from another test we may be equally confident that the corn uses more than twice as much water for grain production as does the wheat. The second comparative figures are unreliable because the soil was relatively overcropped by the corn.

25. Crop tests are subject to such a multitude of local environmental influences that errors in them cannot be regarded as occurring according to the formulas or rules of chance calculated mathematically from purely mechanical observations. The probable error may apply where only accidental variations occur but not where systematic variations exist. Crop tests are subject to systematic variations.

26. In view of the precautions necessary to guard against the invalidating influences of various sources of experimental error, greater and better facilities should be provided experiment stations for the conduct of crop investigations.

27. In crop breeding experiments improvement in yield over the original can only be measured accurately by growing each year some of the original unselected seed for comparison. The method of comparing the results of one period of years with those of another is unreliable. For example, Hogue's Yellow Dent corn which has undergone continuous ear-to-row breeding since 1902 yielded 39 per cent less during the seven-year period 1907-1913 than during the preceding seven years. However, a seven-year comparison with the original seed which has been grown as a check indicates that the inherent yielding power of the ear-to-row and the original corn are almost identical.

28. Soil limitation may be a serious source of error in pot experiments. The relative total moisture-free yields for individual corn plants grown in pots of six sizes in 1914 were, in order from the smallest to the largest, 100, 211, 324.1, 453.6, 643.8, and 747. The corresponding yields of ear corn were 100, 632.5, 1082.3, 2417, 2990, and 4046.7. A uniform application of 1.75 pound of sheep manure per plant (or per pot) increased the yields of total dry matter for the six sizes, in order from the smallest to the largest, 176.4, 95.3, 69.3, 26.1, 12.7, and 7.2 per cent. The corresponding increases in yield of ear corn caused by the manure were 722.5, 193.6, 149.2, 18.9, 14.1, and 2.9 per cent.

In 1915 the relative yields of total dry matter from the six sizes of pots, progressing from the smallest to the largest, were 100, 150, 229.6, 355.6, 586, and 578.7 per cent. The corresponding relative yields of ear corn were 100, 276.2, 819, 1647.5, 2771.3, and 2667.

Applying manure in amounts proportional to the quantity of soil contained, in 1915 had far less striking effect upon the pot yields for the different sizes than when equal quantities were applied in 1914, regardless of the quantity of soil contained.

29. When two, four, or six corn plants were grown in pots of the proper size for growing one normal corn plant, the individual plant yields of total dry matter were respectively 50.8, 26.7, and 16.6 per cent as large as for the one-rate, while the corresponding yields of ear corn were respectively 39.7, 15.9, and 2.8 per cent as large.

30. A review of several hundred experiment station bulletins dealing with variety, fertilizer, cultural, and pot

tests indicates that the statement of methods employed in securing experimental data is often inadequate to acquaint the reader with the manner in which the results were obtained. Such a statement is desirable in order that one may judge regarding the reliability of the results and the degree of confidence which the data merit.

STUDIES CONCERNING THE ELIMINATION OF EXPERIMENTAL ERROR IN COMPARATIVE CROP TESTS

By T. A. Kiesselbach

It is apparent that many sources of error have unconsciously entered into comparative crop yield tests. The very important matter of overcoming variation in soil conditions as a source of experimental error has been quite extensively studied and reported by various investigators during the past decade. The means suggested for reducing such error have been (1) repetition of plats and (2) correction of yields according to check plats planted to a uniform variety or treatment at stated intervals. Both methods have proved of value and a combination of both may often be used advantageously. Some danger always exists of error occurring in the check plats and that correcting according to them may introduce new errors in the yields of crops compared. The method should, for this reason, be used with caution.

Studies in experimental error conducted at this Experiment Station prior to 1911 have been published by Prof. E. G. Montgomery, now of Cornell University, in Bulletin No. 269, of the Bureau of Plant Industry, U. S. Department of Agriculture, and in the Twenty-sixth Annual Report of the Nebraska Agricultural Experiment Station. These published results concern primarily the general problems of repetition and size of nursery small grain plats, and the use of check plats.

The object of the following investigations was to secure further information regarding the elimination of error in comparative yield tests. Shortage of facilities for carrying on this character of work in addition to the regular crop investigations of the Experiment Station has in some cases necessitated intermittent experiments. The duration of some of the tests has for the same reason been shorter than would have been desired.

Acknowledgment is gratefully made to Professor J. A. Ratcliff and Professor C. A. Helm for valuable assistance in field supervision and in keeping records during much of the time these experiments were in progress. Messrs. H. G. Gould, E. R. Ewing, R. E. Holland and H. B. Pier, have also rendered efficient assistance at various times.

ERROR DUE TO COMPETITION BETWEEN ADJACENT PLATS

It is a well known principle in ecology that a keen competition for soil moisture and nutrients may exist between plants which differ in growth habit, when grown in close proximity. Competition between adjacent rows of different varieties, selections, or rates of planting, had suggested itself as a possible source of error in crop tests. An investigation was planned in 1912 to determine the relative merits of rows and blocks for making comparative yield tests in the small grain nursery and in corn experiments.

The question was: Will two varieties give the same comparative yields when planted in alternating rows as when planted in alternating blocks consisting of a number of rows? It was reasonable to assume that there would be less plat-competition between varieties planted in blocks than when planted in single rows.

It has been a common practice in crop breeding experiments to compare the selected strains in adjacent one-row plats for a number of years. Many other comparative tests have also been made in single row plats.

ILLUSTRATION OF PRINCIPLE OF COMPETITION BETWEEN ADJACENT ROWS

On the right-hand side of Fig. 1 is shown a crop of Turkey Red winter wheat planted in the fall of 1912. To the south of this was planted Scotch Fife spring wheat in the spring of 1913. The first row of spring wheat, spaced ten inches from the winter wheat, is seen to have grown only about four inches tall with no grain production. The second row of spring wheat made an almost normal growth, while the third row was entirely normal. The complete failure of the first row of spring wheat may be accounted for by the shortage of both moisture and available plant food material, due to the more rapid and luxuriant growth of the adjacent winter wheat. While this is an extreme example of competition between adjacent rows, it illustrates a principle commonly applying in crop yield tests.

COMPETITION BETWEEN ADJACENT ROWS OF SMALL GRAIN

The plan of the experiment was to plant two crops under comparison in alternating one-row plats and alternating five-row plats. These were replicated 50 times each year in order

Fig. 1—Illustrating principle of competition between adjacent rows. Winter wheat on right; spring wheat on left. Due to competition with the winter wheat, the first row of spring wheat grew only four inches tall with no grain production. The second row was nearly normal and the third row entirely normal.

to eliminate the accidental mechanical and physical errors due to variation in soil, exposure, stand, etc. These nursery rows were spaced 10 inches apart. The relative yields in either the entire five-row block or the three inner rows, as indicated, were regarded as the correct relative yields for the season. A difference in the relative yields when tested in alternating rows, as compared with the relative yields in blocks, is chiefly due to, and measures, the competition between the crops compared in rows. In part of the tests the blocks were harvested as individual rows, which permitted a study of the effect of plat competition upon the border rows of five-row plats. The straw yields as well as the grain yields were also secured in a portion of the tests.

ROW COMPETITION IN RATE-OF-PLANTING TESTS WITH WHEAT AND OATS

During the years 1913 and 1914, both oats and winter wheat were grown at two distinct rates of planting in both

alternating single-row plats and alternating five-row nursery plats, 16 feet in length.

Wheat—Table 1 shows the results with the wheat rate-of-planting tests.

When grown in single rows in 1913, the thin rate yielded 68 per cent as much as the thick rate, while in five-row blocks the thin rate yielded 90 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 24.4 per cent too low. (This percentage effect of competition is determined by dividing the difference between 68 per cent and 90 per cent, or 22, by 90.)

In 1914 the thin rate in rows yielded 35 per cent as much as the thick rate, while in the center three rows of five-row plats it yielded 81 per cent as much as the thick rate. Due to competition, the thin rate yielded 56.8 per cent too low. If the two outside rows are averaged into the block yield, the

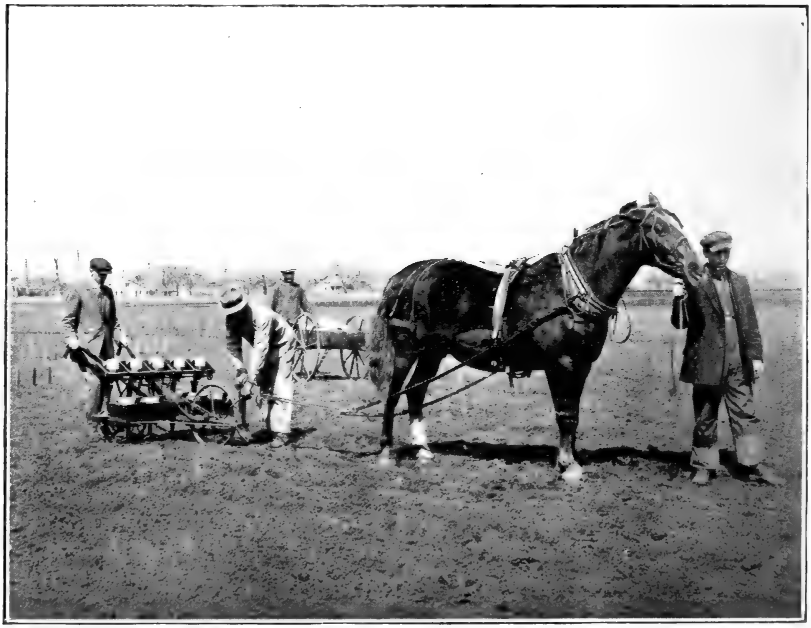


Fig. 2—Method of planting nursery small grain plats with a special nursery drill. The drill can be rapidly adjusted to plant each row at a given rate, independently of the other rows

TABLE 1—*Relative yields of two rates of planting with Turkey Red winter wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Thick rate	Thin rate	Ratio thick to thin	Thick rate	Thin rate	Ratio thick to thin
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	389 ±5.3*	264 ±3.8	100:68	....	....	......
Alternating five-row blocks (average of 50 plats)	394 ±3.2	355 ±2.8	100:90	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	327 ±6.6	115 ±3.6	100:35	1265 ±15.9	494 ±12.2	100:39
Alternating five-row blocks (average of 50 plats)	272 ±4.1	195 ±3.3	100:72	1049 ± 9.5	772 ±7.0	100:74
Two outside rows of block (average of 50 plats)	306 ±5.0	184 ±3.5	100:60	1129 ±11.7	712 ±11.2	100:63
Three inside rows of block (average of 50 plats)	251 ±3.4	203 ±3.6	100:81	994 ± 7.4	812 ±10.0	100:82

*The probable error has been calculated in Tables 1 to 7. For later discussion of the significance of the probable error, see pp. 65-74.

TABLE 2—*Relative yields of two rates of planting with Kherson oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Thick rate	Thin rate	Ratio thick to thin	Thick rate	Thin rate	Ratio thick to thin
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	233 ±4.0	148 ±3.8	100:64	....	....	......
Alternating five row blocks (average of 50 plats)	222 ±2.8	178 ±1.8	100:80	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	220 ±3.6	148 ±2.4	100:67	654 ±5.5	451 ±4.8	100:69
Alternating five-row blocks (average of 50 plats)	205 ±2.6	201 ±2.5	100:98	653 ±4.9	659 ±5.0	100:100.9
Two outside rows of block (average of 50 plats)	209 ±2.1	201 ±3.3	100:96	651 ±7.0	644 ±7.6	100:99
Three inside rows of block (average of 50 plats)	202 ±2.0	207 ±2.2	100:102	657 ±3.5	667 ±3.9	100:102

ratio of thick to thin is 100:72 as compared with 100:81 for the center three rows, while the ratio of thick to thin for the two outside rows only was 100:60. From these data and other similar data it may be concluded that the outside rows of nursery test plats should be discarded.

The straw yields for the 1914 rate-of-planting tests with wheat substantiate the same principles of competition as were brought out in the relative grain yields. In alternating rows, the ratio of thick to thin straw yield was 100:39. For the center three rows of five-row blocks, the ratio was 100:82. The ratio was 100:74 where all five rows were averaged, while it was 100:63 for the two outside rows.

Oats—The relative yields of two rates of planting oats in alternating rows as compared with alternating five-row plats are shown in Table 2. In 1913 the thin rate in rows yielded 64 per cent as much as the thick rate, while in five-row blocks the thin rate yielded 80 per cent as much as the thick rate. Competition in rows with a thicker rate of planting caused the thin rate to yield relatively 20 per cent too low.

In 1914 the thin rate in alternating rows yielded 67 per cent as much as the thick rate, while when compared in the three inner rows of five-row plats the thin rate yielded 2 per cent more than the thick rate. Competition in rows with the thicker rate caused the thin rate of planting to yield relatively 34.3 per cent too low. If the yields of the entire five-row blocks are taken, the ratio of thick to thin is found to have been 100:98 as compared with 100:102 for the three inside rows, while the ratios of thick to thin for the two outside rows was 100:96.

Similar results were obtained from the straw yields in 1914. In alternating single rows the ratio of thick to thin straw yields was 100:69. For the center three rows of five-row blocks the ratio was 100:102. Where all five rows were averaged the ratio was 100:101, while for the two outside rows it was 100:99.

RELATIVE STOOLING OF TWO RATES OF PLANTING WHEN COMPARED IN ALTERNATING ROWS AND ALTERNATING BLOCKS

In 1914, counts were made to determine the effect of competition between alternating rows of two rates of planting wheat and oats upon the relative stooling in the two rates. The counts were made for the plats reported in Tables 1 and 2. The results are given in Table 3.

TABLE 3—*Relative stooling of two rates of planting with Turkey Red Wheat and Kherson oats when compared in alternating one-row plats and alternating five-row plats (1914).*

Character of plats and rate of planting	No. plants in 10 feet of row	No. stools in 10 feet of row	No. stools per plant
WHEAT 1914			
One-row plats			
Thick rate	140	620	4.4
Thin rate	52.5	281	5.4
Ratio thick to thin	100:37	100:45	100:123
Five-row plats (middle 3 rows)			
Thick rate	150	560	3.7
Thin rate	50.5	364	7.2
Ratio thick to thin	100:34	100:65	100:195
OATS 1914			
One-row plats			
Thick rate	195.5	392.5	2.0
Thin rate	100.5	271.0	2.7
Ratio thick to thin	100:51	100:69	100:135
Five-row plats (middle 3 rows)			
Thick rate	195	380	1.9
Thin rate	100	320	3.2
Ratio thick to thin	100:51	100:84	100:168

In the alternating rows of wheat, the actual number of plants per row were in the ratio of 100:37, while in the three inside rows of the five row plats the ratio was 100:34. The number of culms per plant in the alternating thick and thin rows were in the ratio of 100:123, while in the center three rows of the five row plats the ratio was 100:195.

In the case of the oats, the actual number of plants per row were in the ratio of 100:51, both for the alternating rows and for the three inside rows of the five-row blocks. The number of culms per plant in the alternating thick and thin rows were in the ratio of 100:135, while for the center three rows of the five-row plats the ratio was 100:168.

ROW COMPETITION BETWEEN VARIETIES OF WHEAT AND OATS

Wheat—During the years 1913 and 1914, Big Frame winter wheat was compared with Turkey Red winter wheat in both alternating single-row plats and alternating five-row

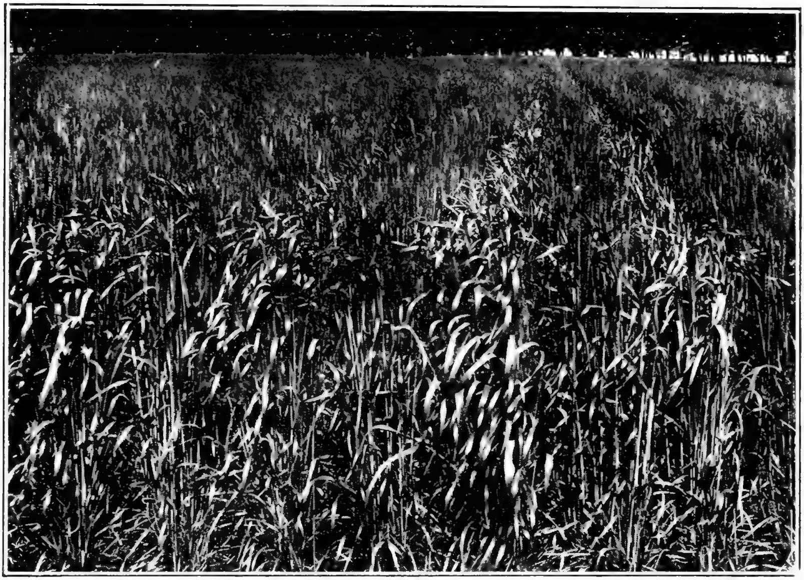


Fig. 3—Competition between two types of wheat in adjacent rows. The single-row method of testing is unreliable

Fig. 4—The "block" method of comparing varieties or selections for yield in the nursery. The two outside rows of each block should be discarded in order to avoid error from competition between adjacent plats. Part of the plats have been harvested

plats. A similar comparison was also made between Turkey Red and Nebraska No. 28 winter wheat.

Turkey Red is the standard bearded hard winter variety for normal Nebraska conditions, while Big Frame is one of the best beardless varieties of rather similar growth habits. The Nebraska No. 28 is an early wheat ripening about ten days before Turkey Red, and is normally six inches shorter. The relative growths of these varieties differ somewhat in different years according to their response to varying climatic conditions. This will account for one variety outyielding in one season, and another variety in a different season. For example, in 1913 the Nebraska No. 28 wheat grew fully as tall as Turkey Red, because it had attained its maximum height before dry weather set in, which somewhat stunted the more slowly developing Turkey Red wheat. The season of 1914 was more favorable for the Turkey Red wheat, which produced a normal, relatively greater vegetative growth.

Table 4 gives the two years' results with Turkey Red and Big Frame wheat. When grown in alternating single rows in 1913, the Big Frame yielded 7 per cent more grain than the Turkey Red wheat, while in alternating five-row plats, the Big Frame yielded 3 per cent less than the Turkey Red. Due to competition, the Big Frame yielded relatively 10.3 per cent too high in single-row plats.

In 1914, the Big Frame yielded 85 per cent as much grain as Turkey Red when compared in alternating one-row plats, while it yielded 97 per cent as much in five-row plats. Competition in rows with Turkey Red caused the Big Frame to yield relatively 12.4 per cent too low.

The straw yields for 1914 give results similar to those for grain. In alternating rows the ratio of Turkey Red to Big Frame straw yields was 100:90. In five-row plats this ratio was 100:97.

Table 5 gives the relative yields of Turkey Red and Nebraska No. 28 wheat during 1913 and 1914. The ratio of Turkey Red to Nebraska No. 28 grain yield was 100:107 in 1913, both when grown in alternating single-row plats and alternating five-row plats. The growth of the two varieties this year was so similar that competition appears to have been a negligible factor.

In 1914 the Nebraska No. 28 yielded 63 per cent as much as the Turkey Red when compared in alternating single-row plats, while it yielded 85 per cent as much in alternating

TABLE 4—*Relative yields of Turkey Red and Big Frame wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Turkey Red	Big Frame	Ratio Turkey Red to Big Frame	Turkey Red	Big Frame	Ratio Turkey Red to Big Frame
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	325 ±4.4	347 ±4.0	100:107	....	....	......
Alternating five-row blocks (average of 50 plats)	408 ±2.6	397 ±2.9	100:97	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	342 ±3.1	290 ±3.6	100:85	981 ±8.2	881 ±6.1	100:90
Alternating five-row blocks (average of 50 plats)	320 ±3.7	310 ±4.0	100:97	993 ±7.7	963 ±7.9	100:97

TABLE 5—*Relative yields of Turkey Red and "Nebraska No. 28" wheat when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Turkey Red	Nebraska No. 28	Ratio Turkey Red to Nebraska No. 28	Turkey Red	Nebraska No. 28	Ratio Turkey Red to Nebraska No. 28
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	365 ±3.9	390 ±3.2	100:107	....	....	......
Alternating five-row plats (average of 50 plats)	396 ±3.3	423 ±2.8	100:107	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	369 ±4.3	232 ±2.7	100:63	1258 ±8.7	669 ±5.6	100:53
Alternating five-row blocks (average of 50 plats)	334 ±4.7	285 ±3.6	100:85	1088 ±8.0	875 ±8.0	100:80
Two outside rows of blocks (average of 50 plats)	....	253 ±3.9	......	....	785 ±7.8	......
Three inside rows of blocks (average of 50 plats)	....	307 ±3.1	......	....	935 ±5.9	......

five-row plats. In rows competition caused the Nebraska No. 28 to yield relatively 25.9 per cent too low. In this test the Nebraska No. 28 five-row plats were harvested as separate rows. The center three rows, free from competition with the ranker growing Turkey Red variety, yielded 21.0 per cent more per row than did the two outside rows. The three inside rows also yielded 7.7 per cent more per row than did the entire five-row plat.

The straw yields for 1914 indicate similar effect of competition. Compared in alternating single-row plats, the ratio of Turkey Red to Nebraska No. 28 straw yields was 100:53, while in five-row plats this ratio was 100:80. The center three rows yielded 19.1 per cent more straw per row than did the two outer rows, which were obliged to compete with Turkey Red. The center three rows also yielded relatively 6.9 per cent more straw per row than did the entire five-row plat with the two outside rows included.

Oats—Both Burt and Swedish Select oats varieties were compared during 1913 and 1914 with Kherson oats in alternating single-row and alternating five-row plats.

Kherson oats is the standard early variety grown at the Nebraska Experiment Station. Burt oats is rather similar in growth habit to the Kherson, ripening at about the same time. The Swedish Select is a somewhat taller variety, ripening about ten days later.

Table 6 gives the two years' results with Kherson and Burt oats. In 1913 the Burt outyielded the Kherson 30 per cent when planted in alternating single rows and 12 per cent in alternating five-row plats. Due to competition the Burt yielded relatively 16 per cent too high in single-row plats.

In 1914 the Burt yielded 39 per cent more than the Kherson in alternating single row plats, while it yielded 1 per cent more in the three center rows of alternating five-row plats. Competition in rows with Kherson oats caused the Burt to yield relatively 37.6 per cent too high. If the yields of the entire five-row plats are taken, the ratio of Kherson to Burt oats is 100:109 as compared with 100:101 for the three inside rows, and 100:120 for the two outside rows.

The straw yields which were obtained for 1914 gave very similar results. In alternating single rows the ratio of Kherson to Burt straw yields was 100:139. For the three inside rows of alternating five-row plats the ratio was 100:109. For the entire five-row plats the ratio was 100:117. For the two outside rows it was 100:129.

TABLE 6—*Relative yields of Kherson and Burt oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Kherson oats	Burt oats	Ratio Kherson to Burt	Kherson oats	Burt oats	Ratio Kherson to Burt
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	201 ±3.6	261 ±3.9	100:130	....	....	......
Alternating five-row blocks (average of 50 plats)	209 ±1.9	234 ±1.9	100:112	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	152 ±2.3	211 ±3.4	100:139	486 ±7.6	676 ±7.4	100:139
Alternating five-row blocks (average of 50 plats)	193 ±2.3	210 ±2.4	100:109	663 ±3.8	773 ±3.9	100:117
Two outside rows of blocks (average of 50 plats)	178 ±3.3	214 ±2.5	100:120	615 ±6.4	793 ±5.3	100:129
Three inside rows of blocks (average of 50 plats)	204 ±2.2	207 ±2.2	100:101	696 ±3.7	760 ±3.3	100:109

TABLE 7—*Relative yields of Kherson and Swedish Select oats when compared in alternating one-row plats and alternating five-row plats (1913-1914)*

Character of plat	Average yield of grain per row			Average yield of straw per row		
	Kherson	Swedish Select	Ratio Kherson to Swedish Select	Kherson	Swedish Select	Ratio Kherson to Swedish Select
	Grams	*Grams*		*Grams*	*Grams*	
YEAR 1913						
Alternating single-row plats (average of 50 plats)	192 ±2.6	157 ±2.5	100:82	....	....	......
Alternating five-row blocks (average of 50 plats)	191 ±1.9	147 ±1.8	100:77	....	....	......
YEAR 1914						
Alternating single-row plats (average of 50 plats)	205 ±3.3	182 ±2.5	100:89	620 ±5.2	698 ±4.8	100:113
Alternating five-row blocks (average of 50 plats)	219 ±2.4	204 ±2.6	100:93	662 ±3.3	744 ±5.2	100:117

Table 7 summarizes the two years' data with Kherson and Swedish Select oats. In 1913 the Swedish Select yielded 18 per cent less than the Kherson when grown in alternating single-row plats, and 23 per cent less in alternating five-row plats. In alternating single rows the Swedish Select yielded relatively 7 per cent too high.

In 1914 the Swedish Select yielded 89 per cent as much grain as Kherson in alternating single-row plats and 93 per cent as much in five-row plats. The Swedish Select straw yielded 13 per cent more in alternating rows and 17 per cent more in five-row plats.

EVIDENCE OF PLAT COMPETITION IN A WHEAT-BREEDING NURSERY

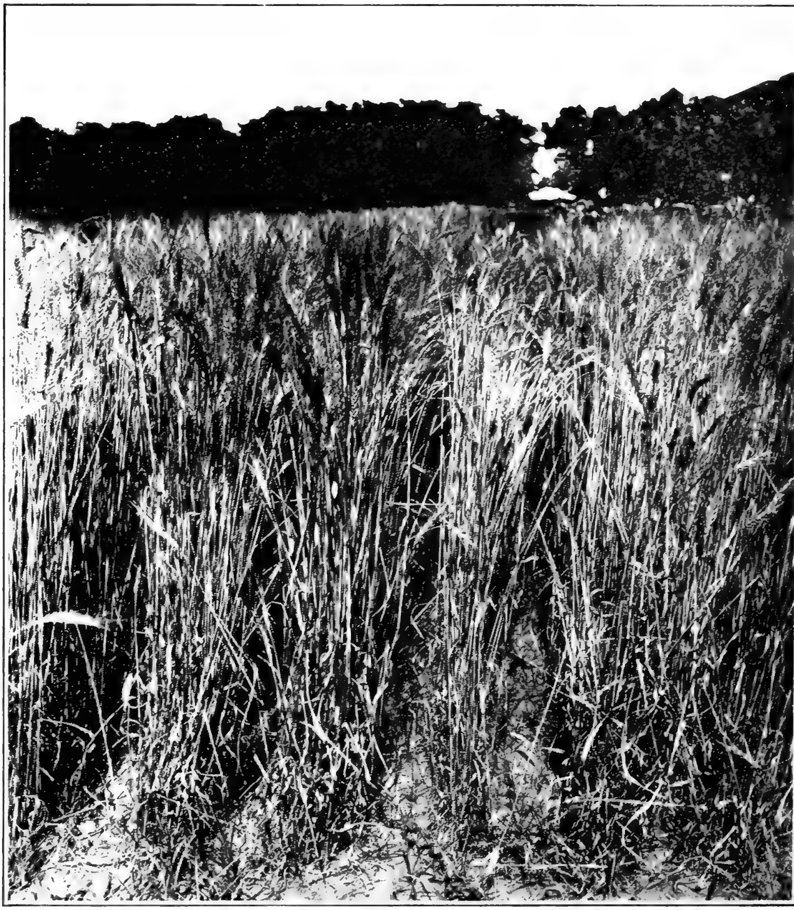
During the four years, 1910, 1911, 1912 and 1914, 80 strains of Turkey Red wheat were tested at the ordinary field rate of seeding in identically the same order each year, in single 16-foot rows ten inches apart. The entire series has been replicated ten times each year. It is probable that many of the yields have been subject to the effect of row competition.

Table 8 contains a concrete example of competition between strains in such a wheat-breeding nursery. In the four-year row test of 80 strains, strain No. 75 ranked 80, while strains No. 74 and No. 76 on either side ranked 1 and 5. Strain No. 75 is a slightly shorter and thinner stooling type. To determine whether the relative rankings of these strains might have been influenced by competition, they were compared in both rows and blocks for two years, 1915-1916.

TABLE 8—*Relative yields of three Turkey Red wheat strains when compared in five-row nursery plats and in single-row plats. Two-year average (1915-1916)*

Strain number	Relative yields	
	Blocks	Rows
GRAIN		
74	106	126
75	100	100
76	108	123
STRAW		
74	110	113
75	100	100
76	102	109

Strain No. 74 was favored 20 per cent and strain No. 76, 15 per cent in yield by being compared (with an adjacent less vigorous type) in rows rather than in blocks. Fig. 5 is a photograph of these strains.



Strain No.: Ck. 74 75 76

Fig. 5—Single-row nursery test plats of Turkey Red Winter wheat. Strain No. 75, in center, is seen to have a lower stooling capacity and is given and unfair test when growing between two high-stooling strains. The two adjacent strains in turn have an unfair advantage

These 80 strains are now all being grown in five-row plats, replicated ten times, for the purpose of establishing the correct relative yields, free from competition as a source of experimental error. Single-row plats are now regarded as unreliable and misleading, because a strain is certain to be unduly favored when grown beside a strain lower in competitive qualities due to such factors as low stooling, slow growing, or partial winterkilling. It is important to have any crop being tested surrounded by a crop of its own kind.

COMPETITION BETWEEN INDIVIDUAL PLANTS

Altho the yields of small grain are never compared by planting alternating seeds of two varieties or two grades of seed in the same row, yet such a comparison may be of interest to throw further light upon the principle of competition.

TABLE 9—*Relative yields, at the normal field rate of planting, of equal numbers of large and small wheat seeds when grown alone in blocks and when grown in competition by alternation in the same row**

Method of comparing large and small seeds	Ratio of yield of small seeds to large seeds		
	Grain	Straw	Total
WINTER WHEAT, 1914			
Grades alone in blocks	90:100	94:100	94:100
Grades competing	61:100	72:100	71:100
WINTER WHEAT, 1915			
Grades alone in blocks	99:100	98:100	98:100
Grades competing	83:100	78:100	79:100
SPRING WHEAT, 1914			
Grades alone in blocks	88:100	93:100	92:100
Grades competing	78:100	78:100	78:100
SPRING WHEAT, 1915			
Grades alone in blocks	80:100	93:100	90:100
Grades competing	82:100	73:100	75:100
AVERAGE FOR WINTER AND SPRING WHEAT, 1914-1915			
Grades alone in blocks	89:100	94:100	93:100
Grades competing	76:100	75:100	76:100

*Compiled from data in Nebraska Research Bulletin No. 11, 1917.

During 1914 and 1915 large and small wheat seeds were planted alternatingly in the row at the normal field rate of planting. Two varieties were used and reciprocated so that the results in Table 9 represent the mean of two varieties for each grade. This reciprocation eliminates largely the varietal effects in the summary. It was necessary to use two distinct varieties (a bearded and a beardless) so that the plants from each grade might be separated at harvest. The same grades were also compared separately in nursery blocks to establish the relative yields when free from competition.

As an average for two varieties each of winter and spring wheat for two years, the small seed in competition yielded relatively 15 per cent too little grain, 20 per cent too little straw, and made 18 per cent too small total yield.

TABLE 10—*Relative yields at the normal field rate of planting, of two varieties when grown alone in blocks, and when grown in competition by alternation in the same row**

Method of comparing varieties		Relative yields: Grain	Straw	Total
WINTER WHEAT, 1914				
Ratio Big Frame to Turkey Red	Alone	90:100	88:100	89:100
	Competition	55:100	70:100	67:100
SPRING WHEAT, 1914				
Ratio Scotch Fife to Marquis	Alone	75:100	93·100	90:100
	Competition	61:100	90:100	86:100
WINTER WHEAT, 1915				
Ratio Big Frame to Turkey Red	Alone	82:100	105:100	99:100
	Competition	120:100	128:100	125:100
SPRING WHEAT, 1915				
Ratio Scotch Fife to Marquis	Alone	95:100	114:100	109:100
	Competition	99:100	125:100	119:100

*Compiled from data in Nebraska Research Bulletin No. 11, 1917.

The results for different years should not be averaged in this variety test, since varieties do not have the same relative competitive qualities in different years. We are interested here in what may happen any one year and not in an average of years.

In similar manner, competition between two varieties planted within the same row was determined. Plants from each variety could be separated at harvest by the presence or absence of beards. The relative yields were also obtained in nursery blocks free from competition by harvesting the

three inside rows of five-row blocks. The results in Table 10 indicate marked competition between varieties. Variety competition amounted to 61 per cent and 46 per cent for winter wheat yields in 1914 and 1915 respectively. For spring wheat this competition equaled 19 per cent and 4 per cent in 1914 and 1915 respectively.

COMPETITION BETWEEN CORN TEST PLATS AS A SOURCE OF EXPERIMENTAL ERROR

In corn variety tests, corn breeding experiments, and various other corn yield tests the crops under comparison have customarily been planted in adjacent plats containing one, two, three, or four rows. The single-row plat is used almost universally in corn breeding experiments. In several instances where only three or four kinds of corn were to be compared, these have all been planted in the same hill, giving each kind of corn a definite position in the hill. This intra-hill method has been employed by Hartley, Brown, Kyle, and Zook (1912) and by Collins (1914).*

Fig. 6—Planting experimental corn plats where accuracy is required. Hand planters are found far superior to planting with a hoe. A stated number of kernels are placed in the planter for each drop

*The year in parentheses following an author's name in the text serves to associate the reference with a particular publication in the Bibliography (pp. 91-94), where the complete title is given.

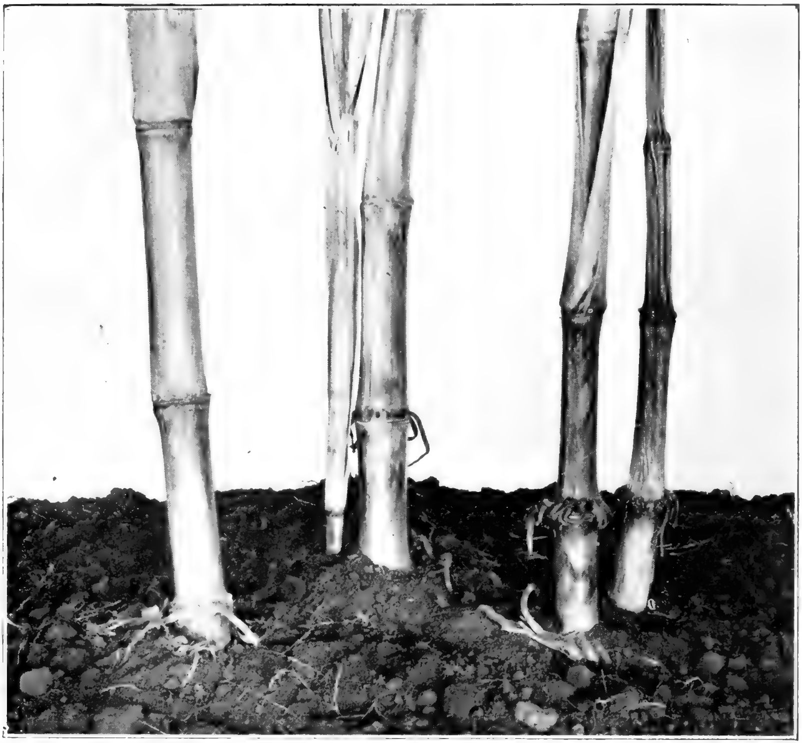


Fig. 7.—A hill of checked corn with the three plants spaced in the hill in order that the plants may be readily counted without suckers being mistaken for separate plants

In 1912 the Nebraska Experiment Station commenced a series of experiments to determine the reliability of the various kinds of corn test plats. The investigations were extended in 1913 but the corn was not harvested because of an almost total crop failure due to deficient rainfall. Good results were secured in 1914, 1915, and 1916.

For planting, the land was marked off into hills three feet, eight inches apart and the corn planted at double the desired rate by means of hand planters. (Fig. 6.) When about four inches high the plants were thinned to the desired rate, thus producing an almost perfect stand. The plants were spaced within the hills so that the original plants could be easily distinguished from suckers. For the comparative yield tests,

50 hills with the desired number of plants and surrounded by a normal stand were harvested from each row. This was accomplished by planting 72 hills in each row, which permitted the elimination of any hills having less than the full stand. Thus all yields were comparable so far as number of plants was concerned. The plats have been replicated eight or more times each year, as indicated in the tables, in order to eliminate soil variations.

ROW COMPETITION IN RATE-OF-PLANTING TESTS WITH CORN

Tables 11, 12, and 13 contain three years' results with planting Nebraska White Prize corn at the rate of two and four plants per hill in alternating single-row and three-row

Fig. 8—A hill of checked corn planted by the ordinary method without spacing the plants in the hill. It contains two plants, altho the number cannot be readily nor accurately determined as with the space-planted hill

TABLE 11—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and in alternating three-row plats (1914)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre: One-row plat or center row		Yield per acre: Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	15	7.4	67.0	43.8	100.0	....
1	2	15	26.6	93.0	35.6	82.0	....
3	4	9	7.1	66.0	38.4	100.0	39.8
3	2	9	32.3	96.0	44.3	116.0	42.4

plats. The rows were harvested separately in the three-row plats.

In 1914 the two-rate yielded 18 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats, the two-rate yielded 16 per cent more than the four-rate. Due to competition with a thicker stand, the two-rate yielded relatively 29.3 per cent too low in alternating single-row plats. In the two outer rows of the three-row plats, the ratio of the four-rate to the two-rate was 100:106.5 as compared with 100:116 for the center rows.

TABLE 12—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and alternating three-row plats (1915)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre: One-row plat or center row		Yield per acre: Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	8	8.5	95	101.7	100.0	....
1	2	8	21.8	110	64.2	63.1	....
3	4	8	11.9	93	90.0	100.0	91.2
3	2	8	29.7	112	62.0	70.0	63.0

In 1915 (Table 12), the two-rate yielded 36.9 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats the two-rate yielded 30 per cent less than the four-rate. Due to competition, the two-rate yielded relatively 9.9 per cent too low in single-row plats. In the two outer rows the ratio of the four-rate to the two-rate was 100:69 as compared with 100:70 for the center rows. Competition was far less marked in 1915 than in 1914 because of much more favorable moisture conditions.

In 1916 (Table 13), the two-rate yielded 21.3 per cent less than the four-rate when compared in alternating single-row plats. In the center rows of alternating three-row plats the two-rate yielded 6.2 per cent less than the four-rate. As the result of competition, the two-rate yielded relatively 16.1 per cent too low in single row plats. In the two outer rows the ratio of the four-rate to the two-rate was 100:85.9 as compared with 100:93.8 for the center rows.

TABLE 13—*Relative yields of two rates of planting with Nebraska White Prize corn when compared in alternating one-row plats and alternating three-row plats (1916)*

No. of rows in plat	No. of plants per hill	No. of replications	No. of suckers per 100 plants	No. of ears per 100 plants	Yield per acre		
					One-row plat or center row		Average of two outside rows
					Bushels	*Per cent*	*Bushels*
1	4	8	24.8	82	52.7	100	....
1	2	8	62.5	107.1	41.5	78.7	....
3	4	8	23.0	79.9	51.8	100	53.4
3	2	8	60.0	115.6	48.6	93.8	45.9

INTRA-HILL AND ROW COMPETITION IN CORN VARIETY YIELD TESTS

During the years 1912 and 1914, Pride of the North corn was compared with Hogue's Yellow Dent corn in (1) alternating single rows, (2) alternating three-row plats, and (3) in the same hill. A similar comparison was also made between University No. 3 corn and Hogue's Yellow Dent in 1914. The relative yields of the above three varieties were also determined by planting all in the same hill.

The relative growth habits of these three varieties during 1914 is shown in Table 14. Hogue's Yellow Dent is a large variety of corn requiring the entire season to mature. Pride of the North is a small, early-maturing variety. University No. 3 is normally somewhat earlier and smaller than Hogue's Yellow Dent.

TABLE 14—*Relative growth characters of three corn varieties used in 1914 (Table 16) to determine the amount of error from variety competition when tested by the single-row and intra-hill methods (1914)*

Variety	Length of growing season	Height of stalk	Leaf-area per plant
	Days	*Inches*	*Sq. In.*
Hogue's Yellow Dent	119	96	997
University No. 3	107	92	940
Pride of the North	92	70	408

Fig. 9—Alternating single-row plats of Hogue's Yellow Dent and Pride of the North corn, 1914. The row method of testing corn types which differ in growth habit is unreliable because of competition between the plats

Fig. 10—Alternating three-row plats of Hogue's Yellow Dent and Pride of the North corn, 1914. Pride of the North on the right. Competition between test plats may be avoided and correct relative yields obtained by discarding the outside rows of three-row plats

In 1912 Hogue's Yellow Dent and Pride of the North corn were grown in alternating single rows and in alternating three-row plats at the rate of three plants per hill in each case. These were also compared for yield by growing one plant of each variety in the same hill. For this reason the variety yields per acre in the hill method are on a different basis than in case of the rows and blocks, but nevertheless they are comparable. The three-row plat tests were replicated 10 times, the single row plats 20 times, and the hills 1,000 times. The results are contained in Table 15.

In alternating three-row plats, Pride of the North yielded 85 per cent as much as Hogue's Yellow Dent, while in alternating single-row plats it yielded 66 per cent as much as the Hogue's Yellow Dent. Within the same hill, Pride of the North yielded 47 per cent as much as Hogue's Yellow Dent. Due to competition Pride of the North yielded relatively 44.7 per cent too low in the same hill, and 22.4 per cent too low in the alternating rows.

In 1914 Hogue's Yellow Dent corn was compared with University No. 3 corn in addition to a comparison with Pride of the North as made in 1912. All three varieties were also compared in the same hill. Plats were replicated the same as in 1912. The results are contained in Table 16.

In the center row of alternating three-row plats, Pride of the North yielded 53 per cent as much as Hogue's Yellow Dent, while in alternating single row plats it yielded 38 per cent as much as Hogue's Yellow Dent. Within the same

Fig. 11—Relative growth of Hogue's Yellow Dent, University No. 3, and Pride of the North corn varieties when grown in the center row of three-row plats (1914)

hill, Pride of the North yielded 26 per cent as much as Hogue's Yellow Dent. Due to competition with Hogue's Yellow Dent in the same hill, Pride of the North yielded relatively 51 per cent too low, while in alternating single-row plats it yielded relatively 28.3 per cent too low.

Comparing the yields of Hogue's Yellow Dent and University No. 3 in the center rows of alternating three-row plats we have a ratio of 100:98, while in alternating single-row plats this ratio was 100:90. In the same hill the ratio

Fig. 12—Relative growth of Hogue's Yellow Dent, University No. 3, and Pride of the North corn varieties when grown in the same hill (1914)

TABLE 15—*Relative yields of corn varieties differing in growth habits, when compared in three-row plats, single-row plats, and when planted in the same hill (1912)*

Varieties* compared and manner of planting	Plants per hill	No. of replications	Yield per acre: Actual: Hogue's Yellow Dent	Yield per acre: Actual: Pride of the North	Yield per acre: Relative: Hogue's Yellow Dent	Yield per acre: Relative: Pride of the North
			Bushels	*Bushels*	*Per cent*	*Per cent*
Hogue's Yellow Dent and Pride of the North alternating in three-row plats	3	10	38.4	32.9	100	85
Hogue's Yellow Dent and Pride of the North alternating in single rows	3	20	50.8	33.7	100	66
Hogue's Yellow Dent and Pride of the North planted in the same hill†	2	1000	26.2	12.2	100	47

*Hogue's Yellow Dent is a standard, large, later-maturing variety of corn, while the Pride of the North used in this test was medium small with a 16-day shorter growth period.

†Where one plant of each of two varieties was grown in the same hill, the actual yield for each variety is given—based on the rate of one plant per hill.

TABLE 16—*Relative yields of corn varieties, differing in growth habits, when compared in three-row plats, single-row plats, and when planted in the same hill (1914)*

Varieties Compared	Three-row blocks: Plants per hill	Three-row blocks: No. of replications	Three-row blocks: Yield per acre: Center row		Three-row blocks: Yield per acre: Two outside rows	Adjacent Single rows: Plants per hill	Adjacent Single rows: No. of replications	Adjacent Single rows: Yield per acre		Planted in same hill: Plants of each variety per hill	Planted in same hill: No. of replications	Planted in same hill: Yield per acre*	
		Plats	*Bus.*	*Per ct.*	*Bus.*		*Plats*	*Bus.*	*Per ct.*		*Hills*	*Bus.*	*Per ct.*
Hogue's Yellow Dent	3	10	63.1	100	68.4	3	20	77.8	100	1	1000	36.9	100
and Pride of the North	3	10	33.7	53	29.1	3	20	29.2	38	1	1000	10.6	26
Hogue's Yellow Dent	3	10	65.8	100	67.3	3	20	68.3	100	1	1000	30.4	100
and University No. 3	3	10	64.7	98	62.6	3	20	61.0	90	1	1000	30.0	99
Hogue's Yellow Dent										1	1000	27.9	100
University No. 3										1	1000	26.7	96
and Pride of the North										1	1000	7.7	28

*Where one plant of each of two or three varieties was grown in the same hill, the actual yield for each variety is given—based on the rate of one plant per hill.

was 100:99. Due to competition, the University No. 3 yielded relatively 8.0 per cent too low, in single rows and within the same hill it yielded 1 per cent too high. The apparent lack of competition within the hill in this case may have been due to there being only two plants of rather similar type in a hill.

When all three varieties were compared in the same hill the relative yields for the Hogue's Yellow Dent, University No. 3, and Pride of the North were respectively 100, 96, and 28, as compared with 100, 98, and 53 in the center rows of three-row plats, and 100, 90, and 38 in single-row plats.

In the three-row plats (Table 16), the yields indicate that competition affects the outer rows to such an extent that they should be discarded in all yield tests of corns which differ in growth habit. Single-row plats are unreliable for a comparative test of corn differing in growth habit or rate of planting. Two-row plats would probably be subject to one-half of the competition of single-row plats.

In 1916 (Table 17), inbred and first generation hybrid Hogue's Yellow Dent corn were similarly compared in (1) alternating single rows, (2) alternating three-row plats, and (3) in the same hill. The inbred corn had been self-fertilized

TABLE 17—*Relative yields of inbred Hogue's Yellow Dent corn and first generation hybrid seed of inbred strains when compared in three-row plats, single-row plats, and when planted in the same hill (1916)*

Manner of planting	Plants per hill	No. of replications	Yield per acre			
			Actual		Relative	
			Crossbred	Inbred	Crossbred	Inbred
			Bushels	*Bushels*	*Per cent*	*Per cent*
Crossbred and inbred strains of H. Y. D. corn alternating in 3-row plats	4	9	76.2	28.1	100	36.9
Crossbred and inbred strains of H. Y. D. corn alternating in single rows	4	6	90.5	28.0	100	31.1
Crossbred and inbred strains of H. Y. D. corn planted in the same hill*	4	300	54.0	11.2	100	20.7

*Where two plants each of two types were grown in the same hill, the actual yield for each type is given, based on the rate of two plants per hill.

TABLE 18—*Summary of relative grain yields when different rates of planting are tested in single-row plats and also in blocks containing several rows*

Crop tested at two rates of planting	Year of test	Ratio thick to thin	
		Alternating rows	Alternating blocks
Turkey Red winter wheat	1913	100:68	100:90
Turkey Red winter wheat	1914	100:35	100:81
Kherson Oats	1913	100:64	100:80
Kherson Oats	1914	100:67	100·102
Nebraska White Prize corn	1914	100:82	100:116
Nebraska White Prize corn	1915	100:63	100:70
Nebraska White Prize corn	1916	100:78	100:93

TABLE 19—*Summary of relative grain yields when different varieties are tested in single-row plats and also in blocks containing several rows*

Varieties compared in alternating rows and in alternating blocks	Year of test	Ratio of variety No. 1 to variety No. 2 in		
		Alternating rows	Alternating blocks	Competing in same hill (Corn)
Turkey Red (1) and Big Frame (2) winter wheat	1913	100:107	100:97	
Turkey Red (1) and Big Frame (2) winter wheat	1914	100:85	100:97	
Turkey Red (1) and Nebraska No. 28 (2) winter wheat	1913	100:107	100:107	
Turkey Red (1) and Nebraska No. 28 (2) winter wheat	1914	100:63	100:85	
Kherson (1) and Burt (2) oats	1913	100:130	100:112	
Kherson (1) and Burt (2) oats	1914	100:139	100:101	
Kherson (1) and Swedish Select (2) oats	1913	100:82	100:77	
Kherson (1) and Swedish Select (2) oats	1914	100:89	100:93	
Hogue's (1) and Pride of the North (2) corn	1912	100:66	100:85	100:47
Hogue's (1) and Pride of the North (2) corn	1914	100:38	100:53	100:26
Hogue's (1) and University No. 3 (2) corn	1914	100:90	100:98	100:99
F_1* Hogue's (1) and inbred Hogue's (2) corn	1916	100:31	100:37	100:21

*First generation hybrid of inbred strains.

for five years and was greatly reduced in size and vigor. The results indicate the error which might be expected if two inbred parents were to be compared with their hybrid and the original check seed. In alternating three-row plats, the inbred corn yielded 36.9 per cent as much as the hybrid seed, while in the alternating single-row plats it yielded 31.1 per cent as much. When compared in the same hill, the inbred seed yielded 20.7 per cent as much as the hybrid seed. Because of competition with the larger plants in the same hill, the inbred corn yielded relatively 44 per cent too low, while in alternating single rows, it yielded relatively 16 per cent too low.

SUMMARY OF PLAT COMPETITION STUDIES

The effects of single row plat competition upon comparative grain yields, are summarized for wheat, oats, and corn, in Tables 18 and 19. These data are taken from Tables 1 to 7 and 11 to 17. The ratios given for the comparative yields in blocks are for the middle row or middle three rows of either three-row plats or five-row plats, except in 1913, when the block-rows were not harvested separately.

VARIATION OF STAND AS A SOURCE OF ERROR IN YIELD TESTS WITH CORN

In order to secure information regarding the effect of variation in stand upon the accuracy of comparative corn tests, 2,000 hills of corn were planted in 1914 and 8,500 hills in 1917, in which were methodically distributed two, one and no-plant hills among hills with a full stand of three plants. Each hill was harvested separately. The results are contained in Tables 20 and 21.

In 1914 (Table 20), when surrounded by hills having a full stand of three plants, the respective relative grain yields of three-plant, two-plant and one-plant hills were 100, 82, and 74. In 1917 the corresponding relative yields were 100, 83, and 50.

In 1914 (Table 21), when three-plant corn hills, otherwise surrounded by a full stand of three plants per hill, were adjacent to (1) one hill with two plants, (2) one hill with one plant, (3) one blank hill, (4) two blank hills, the respective grain yields per hill were 3 per cent, 5 per cent, 13 per cent and 43 per cent greater than when surrounded entirely by three-plant hills.

In 1917 corresponding hills with missing plants increased the grain yields of three-plant hills respectively 2 per cent, 9 per cent, 15 per cent and 25 per cent over the yield of three-plant hills entirely surrounded by three-plant hills.

The data indicate that irregularity of stand in corn yield tests may cause inaccurate yields and should be avoided.

Error due to variation in stand of corn may be largely overcome by planting the corn thick and thinning to a uniform stand soon after coming up. If grown in hills, the seed may be space-planted in the hill so that the actual number of plants may be readily counted at harvest without suckers being mistaken for separate plants. It is desirable, just before husking, to count out a given number of hills having a full stand and surrounded by a normal stand, upon which to base the yield per acre. This may be facilitated by planting an additional number of hills to permit discarding. Space-planting in the hill for experimental yield tests may be accomplished by first marking off the field crosswise with a sled marker and then making three separate spaced plantings in each intersection by means of a hand corn planter adapted for the purpose. Where three plants are grown per hill, the marker runners should be double so that all three plantings may be made in a runner mark, thus insuring uniform planting conditions for all three plants. There are exceptional kinds of corn experiments in which planting thick and thinning to insure a perfect stand would conflict with the object of the investigation.

TABLE 20—*Relative yields of one, two, and three-plant corn hills when surrounded uniformly by three-plant hills (1914 and 1917)*

Number of plants in hills surrounded by uniform three-plant hills	Number of hills averaged	Number of tillers per 100 plants	Number of ears per 100 plants	Average grain yield per hill	
				Actual	Relative
				Grams	*Per cent*
YEAR 1914					
Hills with three plants..	310	8	83	466	100
Hills with two plants...	70	38	96	380	82
Hills with one plant....	16	112	168	344	74
YEAR 1917					
Hills with three plants..	288	....	95	509	100
Hills with two plants...	50	....	102	422	83
Hills with one plant....	64	....	114	252	50

TABLE 21—*Relative yields of three-plant corn hills adjacent to hills with missing plants (1914 and 1917)*

Three-plant hills surrounded by three-plant hills except as indicated below	Number of hills averaged	Number of plants per hill	Number of ears per 100 plants	Average grain yield of three-plant hills	
				Actual	Relative
				Grams	*Per cent*
		YEAR 1914			
Surrounded by hills with three plants	310	3	83.6	465.8	100
Adjacent to one hill with two plants	149	3	87.0	478.2	103
Adjacent to one hill with one plant	44	3	86.3	490.3	105
Adjacent to one blank hill	132	3	88.0	526.6	113
Adjacent to two blank hills	57	3	91.0	666.5	143
		YEAR 1917			
Surrounded by hills with three plants	288	3	95	509	100
Adjacent to one hill with two plants	211	3	96	519	102
Adjacent to one hill with one plant	258	3	102	555	109
Adjacent to one blank hill	234	3	99	585	115
Adjacent to two blank hills	198	3	101	631	125

RELATION OF STAND TO YIELD IN SINGLE-ROW TEST PLATS

The data in Table 22 were compiled from records of extensive ear-to-row tests of Hogue's Yellow Dent corn made by Lyon and Montgomery at the Nebraska Station during the four years 1904-1907. Rows 72 hills in length had been planted by hand at the rate of three kernels per hill, 3 feet 8 inches apart. The entire plats were harvested regardless of the actual stand secured, altho a record was taken of the per cent stand.

In Table 22 the plat yields have been assembled into groups for each year according to the per cent stand. Since a rather large number of plats are averaged in each group, this may overcome in large measure any inherent difference in yielding power of the individual ears tested, and the differ-

TABLE 22—*Relation of per cent germination in the field to yield of single-row test plats of Hogue's Yellow Dent corn (1904-1907)*

Year	Number of plats averaged	Kernels planted per hill	Average field germination	Yield per acre
			Per cent	*Bushels*
GERMINATION 90-95 PER CENT				
1904	10	3	92.1	76.8
1905	9	3	92.3	94.6
1906	2	3	93.0	84.8
1907	22	3	94.0	85.9
Average	43	3	92.8	85.5
GERMINATION 85-90 PER CENT				
1904	12	3	87.6	81.3
1905	25	3	88.1	95.2
1906	10	3	87.0	92.4
1907	16	3	86.0	83.7
Average	63.	3	87.2	88.1
GERMINATION 80-85 PER CENT				
1904	27	3	83.1	75.4
1905	40	3	83.2	88.4
1906	32	3	82.6	85.4
1907	18	3	82.0	85.0
Average	117	3	82.7	83.5
GERMINATION 75-80 PER CENT				
1904	12	3	78.0	76.2
1905	14	3	78.4	85.5
1906	18	3	78.0	83.3
1907	16	3	77.0	83.9
Average	60.	3	77.8	82.2
GERMINATION 70-75 PER CENT				
1904	11	3	74.0	68.1
1905	6	3	73.2	79.9
1906	19	3	73.4	82.9
1907	10	3	72.0	80.6
Average	46.	3	73.1	77.9
GERMINATION 60-70 PER CENT				
1904	13	3	66.2	67.3
1905	3	3	67.3	77.3
1906	10	3	68.1	80.1
1907	10	3	65.0	74.7
Average	36.	3	66.6	74.8
GERMINATION BELOW 60 PER CENT				
1904	21	3	35.6	42.6
1905	6	3	51.5	70.7
1906	11	3	42.1	56.9
1907	7	3	43.0	56.8
Average	45	3	43.0	56.7

ence in yield for the groups may be assigned primarily to the difference in stand. During the four years, considering three plants per hill a 100 per cent stand, stands averaging 92.8, 87.2, 82.7, 77.8, 73.1, 66.6, and 43.0 per cent yielded respectively 85.5, 88.1, 83.5, 82.2, 77.9, 74.8, and 56.7 bushels per acre.

It appears from these results that what was regarded a perfect stand, namely three plants per hill, was too thick for a maximum yield with this variety, since an 87.2 per cent stand outyielded a 92.8 per cent stand. The yield by no means decreased in proportion to the stand. An average stand of 43 per cent yielded 66.3 per cent as much as a 92.8 per cent stand. It would appear unreliable to correct yields upon a basis of stand.

The yield of an individual row plat planted at a given rate will vary greatly according to the stand in adjacent rows. For this reason the data in Table 22 must not be regarded as necessarily indicating the true relative yields, during the years tested, for the different stands as would be obtained in a proper rate-of-planting test.

Because of the chance variations in stand of single-row plats, no reliable formulas can be established for the correction of yields according to the per cent stand. For example, very different results may be expected from a row with 75 per cent stand, according to whether it falls between rows having a 50 per cent or a 100 per cent stand. This is borne out by the rate-of-planting tests in rows and blocks during the three years 1914-1916 (Tables 11, 12, and 13).

COMBINATION OF RATE-PLANTING AND VARIETY YIELD TESTS

It has been a rather common practice in variety yield tests to plant all varieties at one arbitrary "standard" rate, regardless of their growth habits.

During 1907 and 1908, three varieties were tested at five different rates of planting. The Pride of the North and Calico, which are respectively small and medium-sized varieties, increased regularly in yield with the rate of planting, and produced their maximum at the rate of five plants per hill. On the other hand, Mammoth White Pearl, which is a large late corn, yielded its maximum at the three-rate and then fell off sharply.

In 1914, three varieties, differing distinctly in size and length of growing season, were planted at five different rates. Pride of the North produced its maximum yield at the rate of five plants per hill. University No. 3 produced identical and maximum yields at both the two and the three-rate and then fell off sharply. Hogue's Yellow Dent produced its maximum yield at the two-rate and then fell off sharply.

The data in both Tables 23 and Table 24 indicate that the relative yielding power of varieties differing in growth habit can only be determined by planting at several rates. Different varieties have a different optimum rate of planting.

TABLE 23—*Relation of rate of planting to yield of corn varieties differing in growth habit grown in two-row plats* (1907-1908)*

Plants per hill	Length growing period	Yield per acre		
		1907	1908	Average
	Days	*Bushels*	*Bushels*	*Bushels*
PRIDE OF THE NORTH				
1	127	33.7	25.0	29.3
2	126	48.2	37.5	42.8
3	126	55.3	45.5	50.0
4	125	63.8	51.6	57.7
5	125	69.4	48.4	58.9
CALICO				
1	127	43.1	28.1	35.6
2	126	53.4	40.6	47.0
3	126	71.0	53.1	62.0
4	125	74.8	56.2	65.5
5	124	78.7	64.1	71.4
MAMMOTH WHITE PEARL				
1	135	45.6	43.8	44.7
2	135	59.1	65.6	62.3
3	134	70.7	71.9	71.3
4	133	52.0	59.4	55.7
5	133	61.1	56.2	58.6

*Plats not duplicated.

EFFECT OF REMOVING SUCKERS WITH DIFFERENT VARIETIES

Occasionally an investigator has removed the suckers from his corn varieties or selections in order to avoid annoyance by them. The data in Table 25 indicate that the removal of suckers may affect different varieties differently, and that a new error in testing may be introduced thereby.

TABLE 24—*Relation of rate of planting to yield of corn varieties differing in growth habit grown in three-row plats (1914)*

Plants per hill	No. of replications	Length growing Period	Barren stalks	Two-eared stalks	No. of ear bearing suckers per 100 plants	Yield per acre (center row)
		Days	*Per cent*	*Per cent*		*Bushels*
		PRIDE OF THE NORTH				
1	3	92	0	8	7	17.4
2	3	92	0	1	2	28.2
3	3	92	2	0	0	35.5
4	3	92	2	0	0	39.8
5	3	92	8	0	0	44.4
		UNIVERSITY NO. 3				
1	3	107	0	14	20	40.2
2	3	107	1	3	2	59.6
3	3	107	6	1	0	59.5
4	3	107	8	0	0	52.7
5	3	107	15	0	0	47.3
		HOGUE'S YELLOW DENT				
1	3	119	0	10	19	44.4
2	3	119	1	1	2	63.9
3	3	119	2	0	0	59.0
4	3	119	7	0	0	59.8
5	3	119	13	0	0	53.7

RELIABILITY OF ESTIMATING PLAT YIELDS BY MEANS OF FRACTIONAL AREAS

In conducting field experiments in cooperation with farmers, experiment stations frequently encounter difficulty in having test plats properly harvested and threshed. In some states the yields of such plats are estimated by harvesting a number of very small apparently representative areas from each of the plats to be compared. The small quantity

TABLE 25—*Effect of removing tillers from corn varieties differing in growth habits (1912 and 1914)*

Variety	Plants per hill	No. of replications	Yield per acre*		
			Tillers on	Tillers removed	Difference
			Bushels	*Bushels*	*Bushels*
YEAR 1912					
Pride of the North	2	10	38.6	30.9	7.7
University No. 3	2	10	47.7	42.9	4.8
Hogue's Yellow Dent	2	10	53.7	43.5	10.2
Pride of the North	3	10	40.9	38.2	2.7
University No. 3	3	10	56.9	54.2	2.7
Hogue's Yellow Dent	3	10	43.6	38.8	4.8
YEAR 1914					
Pride of the North	2	3	35.3	32.5	2.8
University No. 3	2	3	49.2	50.5	+1.3
Hogue's Yellow Dent	2	3	52.3	55.0	+2.7
Pride of the North	3	3	38.8	33.6	5.2
University No. 3	3	3	45.8	46.6	+0.8
Hogue's Yellow Dent	3	3	54.4	54.3	0.1

*Yield per acre based on center row of three-row plats in 1914 and on single-row plats in 1912.

of grain harvested in this manner can readily be shipped to the central station for threshing and estimation of yield. In order to secure information relative to the reliability of such a method the following test was made in 1917:

Duplicate thirtieth-acre field plats of each of seven different varieties or selections of winter wheat were chosen from among a large number of plats for this study. These plats measured 16 rods by 66 inches and contained eight rows.

Twenty systematically distributed fractional areas or quadrates were harvested from each plat. These were 32 inches square, contained four rows of wheat, and were .0001632 acre in area. Quadrates were located 10 feet from each end and at intervals of 14 feet on alternate sides of the plat, as indicated in the following diagram.

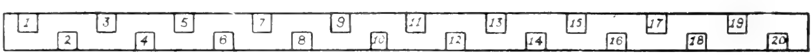
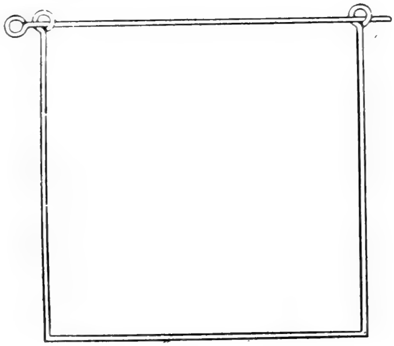


Diagram showing distribution of 20 quadrates in thirtieth-acre plats (Table 26)

The quadrates were accurately laid out by means of an iron frame, as shown in the following figure. A rectangular frame is more reliable than a round one where the grain is planted in rows.



Frame used for laying off quadrates (Table 26)

Because of severe and variable winterkilling the 14 plats differed markedly in the percentage of plants surviving, and in yield. There was also much greater variation between the quadrates within a single plat than would normally be expected.

Opportunity was provided to compare the mean results of 5, 10, and 20 systematically distributed quadrates with the entire plat from which they were harvested. In making four groups of five quadrates each, group (a) contained quadrates Nos. 1, 6, 9, 14, and 17; group (b) contained Nos. 3, 8, 11, 16, and 19; group (c) contained Nos. 2, 5, 10, 13, and 18; and group (d) Nos. 4, 7, 12, 15, and 20. For two groups of 10 quadrates each, group (a) contained Nos. 1, 4, 5, 8, 9, 12, 13, 16, 17, and 20, and group (b) contained Nos. 2, 3, 6, 7, 10, 11, 14, 15, 18, and 19. The results of these various groupings are shown in Table 26 in comparison with the yields of the entire respective plats.

The average yield determined from 20 quadrates deviated 1.4 bushels from the average plat yield.

For individual plats the 20-quadrate yield estimation varied from 0.2 to 3.2 bushels per acre.

Since each kind of wheat was grown in duplicate plats the mean of 40 quadrates can be compared with the mean of two field plats. In this comparison the average of these

TABLE 26—*Comparative yield of grain per acre from winter wheat plats and from systematically distributed fractional areas harvested within the plats (1917)*

CLASSIFICATION	Group number	Turkey Red No. 42		Turkey Red No. 48		Turkey Red No. 6		Turkey Red No. 60		Turkey Red No. 78		Original Turkey Red		Kharkov	
		Plat 2	Plat 30	Plat 3	Plat 31	Plat 4	Plat 32	Plat 10	Plat 38	Plat 12	Plat 40	Plat 13	Plat 41	Plat 22	Plat 50
		Bus.	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*	*Bus.*
Field Plat		27.9	41.2	33.2	41.8	35.4	44.3	40.3	49.2	15.1	20.9	35.7	38.5	34.0	37.4
Five quadrates in a group	a	29.2	41.0	28.8	45.3	35.1	51.3	40.9	45.7	10.3	24.2	42.3	44.1	38.2	35.3
	b	27.9	42.1	35.4	45.5	33.0	48.0	39.3	49.5	11.3	25.8	31.4	35.9	38.1	38.5
	c	26.4	41.5	30.1	40.6	32.5	36.0	35.1	47.7	9.1	14.0	35.8	44.1	34.8	41.8
	d	29.7	41.1	31.2	39.8	38.6	44.1	35.3	49.1	18.0	28.7	35.6	33.2	37.9	38.4
Average		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Ten quadrates in a group	a	31.1	38.5	32.1	43.2	36.9	45.5	38.8	45.4	13.1	25.0	37.8	38.6	39.3	36.8
	b	25.5	44.3	30.6	42.4	32.7	44.2	36.5	50.5	11.3	21.4	34.7	40.1	35.2	40.1
Average		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Twenty quadrates in a group		28.3	41.4	31.3	42.8	34.8	44.8	37.6	48.0	12.2	23.2	36.3	39.3	37.2	38.5
Average of two field plats		34.5		37.5		39.8		44.7		18.0		37.1		35.7	
Average of 40 quadrates		34.8		37.1		39.8		42.8		17.7		37.8		37.8	
Deviation of quadrates from field plats		+ 0.3		— 0.4		0.0		— 1.9		— 0.3		+ 0.7		+ 2.1	

quadrate means, for the several sorts of wheat, deviated 2.2 per cent from the average of the duplicate plat yields.

When the quadrates from each plat were grouped into sets of five and ten each, there was considerable variation in yield between the separate groups, which suggests that not less than 20 quadrates should be harvested from comparative plats of this character.

It appears that the results from 20 systematically distributed quadrates may be fairly safely substituted for the yield of the entire plat from which they are taken.

EXPERIMENTAL ERRORS CAUSED BY SOIL VARIATION

The lack of uniformly productive land for comparative crop tests has given rise to a number of methods frequently used for ascertaining and overcoming the resultant experimental error. Chief among these methods are: (1) The use of frequent, systematically distributed check plats planted to a uniform crop for the purpose of (a) indicating the degree

Fig. 13—A relatively uniform field containing 207 thirtieth-acre plats sown for a method study to a uniform crop of Kherson oats (1916)

of variation due to the soil or (b) correcting the results from the intervening test plats. (2) Replication of plats and basing the conclusions upon the mean yield. (3) Use of long, narrow rather than short, wide plats. (4) Calculating the probable error for the mean results of replicated plats, to indicate the degree of confidence which may be placed in the results.

The results from 207 thirtieth-acre Kherson oats plats, grown in 1916, illustrate each of the four practices mentioned above. These plats were planted to a uniform crop upon a seemingly uniform field for the purpose of studying variation in plat yields as a source of experimental error. The

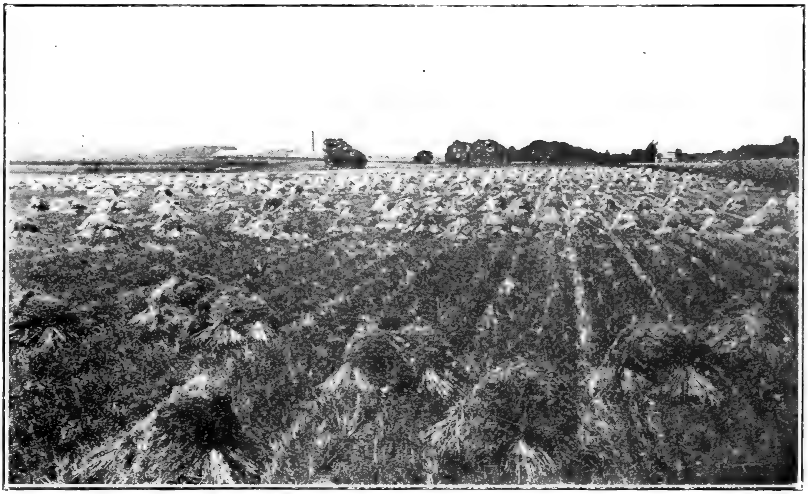


Fig. 14—Two hundred and seven thirtieth-acre Kherson oats plats planted to a uniform crop for studying experimental error in 1916

entire field had been cropped uniformly to silage corn for a period of eight years. It had been plowed each year and was also plowed in preparation for the oats in 1916. The oats were drilled during two successive days in plats 16 rods by 66 inches, which equaled one drill width. The plats were separated by a space of 16 inches between outside drill rows. A wide discard border of oats was grown around the outer edge of the field, so that all plats should have a similar exposure. General views of this field are shown in Figures 13 and 14.

USE OF CHECK PLATS

During the past 15 years it has become the general practice in crop investigations to plant check plats at regular stated intervals. These plats are planted to a uniform crop and should yield alike except for various environmental sources of experimental error.

The use of check plats may be twofold: (1) To indicate the error caused by variation in normal plat yields. The variation in the check plats is regarded as indicative of the error in the test plats. (2) Check plats are more commonly used to calculate the normal or theoretical yield of all plats in the field. All crops or treatments are then compared directly with each other by their increased or decreased yield above or below the calculated normal yield for the plats upon which they grew. This difference is best expressed in percentage of the normal plat yield. Comparative yields per acre may then be calculated for each crop, variety, or treatment by adding (or subtracting) the difference between it and the normal yield for the plat to (or from) the mean yield for all check plats in the field. This recalculation of yields is usually spoken of as correction according to check plats.

The check plats may be variously distributed in the field according to the manner in which the corrections are to be made. Three methods of correction are in common use: (1) The normal or theoretical yield of the test plat is determined by, and is equivalent to, the average of two adjacent check plats. (Alternating plats are check plats.) (2) The normal or theoretical yield of the test plat is determined by, and is equivalent to, the yield of a single adjacent check plat. (Two test plats are planted between checks.) (3) The soil between two or more check plats is regarded as varying gradually from one check plat to the other and a progressive correction is used to establish the normal or theoretical yields of the intervening test plats. Thus, if two test plats lie between checks which yield 51 and 60 bushels respectively, the normal yields assigned to the two test plats by this progressive method would be 54 and 57 bushels. Progressing from the lower to the higher yielding check the normal yield of the first test plat is greater than the poorer check by one-third of the difference, while the normal yield of the second test plat is greater than the poorer check by two-thirds of the difference. The proportion of the difference added to each successive test plat will depend upon the number of plats between checks.

TABLE 27—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show use of alternating check plats for correction of yields**

Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal					Actual	Normal					Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1 ck	75.5				78.2	138 ck	87.2				78.2	139 ck	81.6				78.2
2	84.8	80.9	+ 3.9	+ 4.82	82.0	137	81.9	86.0	— 4.1	— 4.77	74.5	140	83.0	82.8	+ 0.2	+ 0.24	78.4
3 ck	86.3				78.2	136 ck	84.8				78.2	141 ck	83.9				78.2
4	84.4	85.6	— 1.2	— 1.40	77.1	135	84.4	86.0	— 1.6	— 1.86	76.8	142	75.5	80.6	— 5.1	— 6.33	73.3
5 ck	84.8				78.2	134 ck	87.2				78.2	143 ck	77.3				78.2
6	85.3	83.2	+ 2.1	+ 2.52	80.2	133	82.0	86.3	— 4.3	— 4.98	74.3	144	76.9	77.1	— 0.2	— 0.26	78.0
7 ck	81.6				78.2	132 ck	85.3				78.2	145 ck	76.9				78.2
8	84.8	80.9	+ 3.9	+ 4.82	82.0	131	82.0	81.3	+ 0.7	+ .86	78.9	146	82.0	76.0	+ 6.0	+ 7.90	84.4
9 ck	80.2				78.2	130 ck	77.3				78.2	147 ck	75.0				78.2
10	79.7	79.7	0.0	0.0	78.2	129	79.8	78.8	+ 1.0	+ 1.27	79.2	148	75.5	75.3	+ 0.2	+ 0.27	78.4
11 ck	79.2				78.2	128 ck	80.2				78.2	149 ck	75.5				78.2
12	83.0	79.7	+ 3.3	+ 4.14	81.4	127	82.2	72.5	+ 9.7	+13.38	88.7	150	74.1	72.7	+ 1.4	+ 1.93	79.7
13 ck	80.2				78.2	126 ck	64.7				78.2	151	69.8				78.3
14	86.3	80.7	+ 5.6	+ 6.94	83.6	125	70.8	72.0	— 1.2	— 1.67	76.9	152	71.7	73.8	— 2.1	— 2.85	76.0
15 ck	81.1				78.2	124 ck	79.2				78.2	153 ck	77.8				78.2
16	77.8	78.3	— 0.5	— .64	77.7	123	77.8	77.4	+ 0.4	+ .52	78.6	154	75.9	75.3	+ 0.6	+ .80	78.8
17 ck	75.5				78.2	122 ck	75.5				78.2	155 ck	72.7				78.2
18	68.4	77.2	— 8.8	—11.40	69.3	121	88.1	81.6	+ 6.5	+ 7.97	84.4	156	73.1	73.9	— 0.8	— 1.08	77.4
19 ck	78.8				78.2	120 ck	87.7				78.2	157 ck	75.0				78.2
20	80.6	80.7	— 0.1	— .12	78.1	119	88.6	84.7	+ 3.9	+ 4.60	81.8	158	78.8	76.0	+ 2.8	+ 3.68	81.1
21 ck	82.5				78.2	118 ck	81.6				78.2	159 ck	76.9				78.2
22	85.3	80.7	+ 4.6	+ 5.70	82.7	117	85.3	81.8	+ 3.5	+ 4.28	81.5	160	72.7	76.4	— 3.7	— 4.84	74.4
23 ck	78.8				78.2	116 ck	82.0				78.2	161 ck	75.9				78.2
24	80.2	78.8	+ 1.4	+ 1.78	79.6	115	75.0	79.0	— 4.0	— 5.06	74.2	162	75.9	78.3	— 2.4	— 3.07	75.8
25 ck	78.8				78.2	114 ck	75.9				78.2	163 ck	80.6				78.2
26	85.8	71.8	+14.0	+19.50	93.5	113	89.1	80.2	+ 8.9	+11.10	86.9	164	78.8	78.3	+ 0.5	+ .64	78.7
27 ck	64.7				78.2	112 ck	84.4				78.2	165 ck	75.9				78.2
28	88.1	70.8	+17.3	+24.44	97.3	111	86.3	86.3	0.0	0.0	78.2	166	75.5	73.6	+ 1.9	+ 2.58	80.2
29 ck	76.9				78.2	110 ck	88.1				78.2	167 ck	71.3				78.2
30	83.4	78.8	+ 4.6	+ 5.84	82.8	109	79.2	84.4	— 5.2	— 6.16	73.4	168	72.2	72.0	+ 0.2	+ .28	78.4
31 ck	80.6				78.2	108 ck	80.6				78.2	169 ck	72.7				78.2
32	79.7	82.0	— 2.3	— 2.81	76.0	107	86.7	81.1	+ 5.6	+ 6.91	83.6	170	72.2	75.0	— 2.8	— 3.73	75.3
33 ck	83.4				78.2	106 ck	81.6				78.2	171 ck	77.3				78.2

34	81.1	83.0	— 1.9	— 2.29	76.4	105	82.0	81.6	+ 0.4	+ .49	78.6	172	78.3	78.1	+ 0.2	+ .26	78.4
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	81.1	— 0.9	— 1.11	77.3	103	89.5	78.8	+10.7	+13.58	88.8	174	75.9	78.8	— 2.9	—3.68	75.3
37 ck	79.7				78.2	102 ck	75.9				78.2	175 ck	78.8				78.2
38	81.6	81.6	0.0	0.0	78.2	101	71.3	74.8	— 3.5	— 4.68	74.5	176	80.6	74.8	+ 5.8	+ 7.75	84.3
39 ck	83.4				78.2	100 ck	73.6				78.2	177 ck	70.8				78.2
40	78.8	85.1	— 6.3	— 7.40	72.4	99	83.0	71.3	+11.7	+16.41	91.0	178	72.7	74.6	— 1.9	— 2.55	76.2
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	86.3	— 3.8	— 4.40	74.8	97	73.6	76.7	— 3.1	— 4.04	75.0	180	77.3	80.0	— 2.7	— 3.38	75.6
43 ck	85.8				78.2	96 ck	84.4				78.2	181 ck	81.6				78.2
44	78.8	82.8	— 4.0	— 4.83	74.4	95	76.9	83.2	— 6.3	— 7.57	72.3	182	74.1	78.6	— 4.5	— 5.73	73.7
45 ck	79.7				78.2	94 ck	82.0				78.2	183 ck	75.5				78.2
46	69.4	79.3	— 9.9	—12.48	68.4	93	71.7	77.4	— 5.7	— 7.36	72.4	184	72.7	78.8	— 6.1	— 7.74	72.2
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	79.3	+ 2.7	+ 3.41	80.9	91	74.5	72.9	+ 1.6	+ 2.19	79.9	186	65.6	76.7	—11.1	—14.47	66.9
49 ck	79.7				78.2	90 ck	73.1				78.2	187 ck	71.3				78.2
50	82.5	82.5	0.0	0.0	78.2	89	71.3	70.1	+ 1.2	+ 1.71	79.5	188	64.7	70.8	— 6.1	— 8.62	71.5
51 ck	85.3				78.2	88 ck	67.0				78.2	189 ck	70.3				78.2
52	83.9	84.4	— 0.5	— .59	77.7	87	67.0	73.6	— 6.6	— 8.97	71.2	190	68.4	73.1	— 4.7	— 6.43	73.2
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	79.2	+ 2.4	+ 3.03	80.6	85	70.3	78.8	— 8.5	—10.79	69.8	192	79.2	72.7	+ 6.5	+ 8.94	85.2
55 ck	75.0				78.2	84 ck	77.3				78.2	193 ck	69.4				78.2
56	75.0	79.2	— 4.2	— 5.30	74.1	83	73.6	79.2	— 5.6	— 7.07	72.7	194	73.1	68.2	+ 4.9	+ 7.19	83.8
57 ck	83.4				78.2	82 ck	81.1				78.2	195 ck	67.0				78.2
58	85.3	79.9	+ 5.4	+ 6.76	83.5	81	73.6	78.1	— 4.5	— 5.76	73.7	196	82.5	69.2	+13.3	+19.22	93.2
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	79.0	— 9.6	—12.15	68.7	79	78.8	77.1	+ 1.7	+ 2.20	79.9	198	71.3	64.0	+ 7.3	+11.41	87.1
61 ck	81.6				78.2	78 ck	79.2				78.2	199 ck	56.7				78.2
62	78.3	80.7	— 2.4	— 2.97	75.9	77	81.1	86.0	— 4.9	— 5.70	73.7	200	57.7	60.3	— 2.6	— 4.31	74.8
63 ck	79.7				78.2	76 ck	92.8				78.2	201 ck	63.8				78.2
64	80.6	79.5	+ 1.1	+ 1.38	79.3	75	79.2	88.8	— 9.6	—10.81	69.7	202	66.6	67.1	— 0.5	— 0.75	77.6
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	78.1	— 1.2	— 1.54	77.0	73	82.5	86.5	— 4.0	— 4.62	74.6	204	68.4	75.1	— 6.7	— 8.92	71.2
67 ck	76.9				78.2	72 ck	88.1				78.2	205 ck	79.8				78.2
68	83.0	75.3	— 7.7	—10.23	70.2	71	85.3	83.5	+ 1.8	+ 2.16	79.9	206	78.8	77.4	+ 1.4	+ 1.81	79.6
69 ck	73.6				78.2	70 ck	78.8				78.2	207 ck	75.0				78.2

*The plats are arranged in this table in the same relative position as they occurred in the field.

TABLE 28—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show use of one adjacent check plat for correction of yields*

Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal					Actual	Normal					Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1	75.5	84.3	— 9.3	—10.97	69.6	138	87.2	89.1	— 1.9	— 2.13	76.5	139	81.6	83.0	— 1.4	— 1.69	76.9
2 ck	84.8				78.2	137 ck	89.1				78.2	140 ck	83.0				78.2
3	86.3	84.8	+ 1.5	+ 1.77	79.6	136	84.8	89.1	— 4.3	— 4.83	74.4	141	83.9	83.0	+ 0.9	+ 1.08	79.0
4	84.4	84.8	— 0.4	— 0.47	77.8	135	84.4	87.2	— 2.8	— 3.21	75.7	142	75.5	77.3	— 1.8	— 2.33	76.4
5 ck	84.8				78.2	134 ck	87.2				78.2	143 ck	77.3				78.2
6	85.3	84.8	+ 0.5	+ 0.59	78.7	133	82.0	87.2	— 5.2	— 5.96	73.5	144	76.9	77.3	— 0.4	— .52	77.8
7	81.6	84.8	— 3.2	— 3.77	75.3	132	85.3	82.0	— 3.3	+ 4.02	81.3	145	76.9	82.0	— 5.1	— 6.22	73.3
8 ck	84.8				78.2	131 ck	82.0				78.2	146 ck	82.0				78.2
9	80.2	84.8	— 4.6	— 5.42	74.0	130	77.3	82.0	— 4.7	— 5.73	73.7	147	75.0	83.0	— 7.0	— 8.54	71.5
10	79.7	79.2	+ 0.5	+ 0.63	78.7	129	79.8	80.2	— 0.4	— 0.50	77.8	148	75.5	75.5			78.8
11 ck	79.2				78.2	128 ck	80.2				78.2	149 ck	75.5				78.2
12	83.0	79.2	+ 3.8	+ 4.80	82.0	127	82.2	80.2	+ 2.0	+ 2.49	80.1	150	74.1	75.5	— 1.4	— 1.85	76.8
13	80.2	86.3	— 6.1	— 7.07	72.7	126	64.7	70.8	— 6.1	— 8.62	71.5	151	69.8	71.7	— 1.9	— 2.65	76.1
14 ck	86.3				78.2	125 ck	70.8				78.2	152 ck	71.7				78.2
15	81.1	86.3	— 5.2	— 6.03	73.5	124	79.2	70.8	+ 8.4	+11.86	87.5	153	77.8	71.7	+ 6.1	+ 8.51	84.9
16	77.8	75.5	+ 2.3	+ 3.05	80.6	123	77.8	75.5	+ 2.3	+ 3.05	80.6	154	75.7	75.9	+ 3.2	+ 4.40	81.6
17 ck	75.5				78.2	122 ck	75.5				78.2	155 ck	72.7				78.2
18	68.4	75.5	— 7.1	— 9.40	70.9	121	88.1	75.5	+12.6	+16.69	91.3	156	73.1	72.7	+ 0.4	+ .55	78.6
19	78.8	80.6	— 1.8	— 2.23	76.5	120	87.7	88.6	— 0.9	— 1.02	77.4	157	75.0	78.8	— 3.8	— 4.82	74.4
20 ck	80.6				78.2	119 ck	88.6				78.2	158 ck	78.8				78.2
21	82.5	80.6	+ 1.9	+ 2.36	80.1	118	81.6	88.6	— 7.0	— 7.90	72.0	159	76.9	78.8	— 1.9	— 2.41	76.3
22	85.3	78.8	+ 6.5	+ 8.25	84.7	117	85.3	82.0	+ 3.3	+ 4.02	81.3	160	72.7	75.9	— 3.2	— 4.22	74.9
23 ck	78.8				78.2	116 ck	82.0				78.2	161 ck	75.9				78.2
24	80.2	78.8	+ 1.4	+ 1.78	79.6	115	75.0	82.0	— 7.0	— 8.54	71.5	162	75.9	75.9			78.2
25	78.8	85.8	— 7.0	— 8.16	71.8	114	75.9	89.1	—13.2	—14.81	66.6	163	80.6	78.8	+ 1.8	+ 2.28	80.0
26 ck	85.8				78.2	113 ck	89.1				78.2	164 ck	78.8				78.2
27	64.7	85.8	—21.1	—24.59	59.0	112	84.4	89.1	— 4.7	— 5.28	74.1	165	75.9	78.8	— 2.9	— 3.68	75.3
28	88.1	76.9	+11.2	+14.56	89.6	111	86.3	88.1	— 1.8	— 2.04	76.6	166	75.5	71.3	+ 4.2	+ 5.89	82.8
29 ck	76.9				78.2	110 ck	88.1				78.2	167 ck	71.3				78.2
30	83.4	76.9	+ 6.5	+ 8.45	84.8	109	79.2	88.1	— 8.9	—10.10	70.3	168	72.2	71.3	+ 0.9	+ 1.26	79.2
31	80.6	79.7	+ 0.9	+ 1.13	79.1	108	80.6	86.7	— 6.1	— 7.04	72.7	169	72.7	72.2	+ 0.5	+ 0.69	78.7
32 ck	79.7				78.2	107 ck	86.7				78.2	170 ck	72.2				78.2
33	83.4	79.7	+ 3.7	+ 4.64	81.8	106	81.6	86.7	— 5.1	— 5.88	73.6	171	77.3	72.2	+ 5.1	+ 7.06	83.7

34	81.1	82.5	— 1.4	— 1.70	76.9	105	82.0	81.6	+ 0.4	+ 0.49	78.6	172	78.3	78.8	— 0.5	— 0.63	77.7
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	82.5	— 2.3	— 2.79	76.0	103	89.5	81.6	+ 7.9	+ 9.68	85.8	174	75.9	78.8	— 2.9	— 3.68	75.3
37	79.7	81.6	— 1.9	— 2.33	76.4	102	75.9	71.3	+ 4.6	+ 6.45	83.3	175	78.8	80.6	— 1.8	— 2.23	76.5
38 ck	81.6				78.2	101 ck	71.3				78.2	176 ck	80.6				78.2
39	83.4	81.6	+ 1.8	+ 2.21	79.9	100	73.6	71.3	+ 2.3	+ 3.23	80.7	177	70.8	80.6	— 9.8	—12.16	68.7
40	78.8	86.7	— 7.9	— 9.11	71.1	99	83.0	68.9	+14.1	+20.47	94.2	178	72.7	78.3	— 5.6	— 7.15	72.6
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	86.7	— 4.2	— 4.84	74.4	97	73.6	68.9	+ 4.7	+ 6.82	83.5	180	77.3	78.3	— 1.0	— 1.28	77.2
43	85.8	78.8	+ 7.0	+ 8.88	85.1	96	84.4	76.9	+ 7.5	+ 9.75	85.8	181	81.6	74.1	+ 7.5	+10.12	86.1
44 ck	78.8				78.2	95 ck	76.9				78.2	182 ck	74.1				78.2
45	79.7	78.8	+ 0.9	+ 1.14	79.1	94	82.0	76.9	+ 5.1	+ 6.63	83.4	183	75.5	74.1	+ 1.4	+ 1.89	79.7
46	69.4	78.8	— 9.4	—11.93	68.9	93	71.7	72.7	— 1.0	— 1.38	77.1	184	72.7	82.0	— 9.3	—11.34	69.3
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	78.8	+ 4.2	+ 5.33	82.4	91	74.5	72.7	+ 1.8	+ 2.48	80.1	186	65.6	82.0	—16.4	—20.00	62.6
49	79.7	82.5	— 2.8	— 3.39	75.5	90	73.1	71.3	+ 1.8	+ 2.52	80.2	187	71.3	64.7	+ 6.6	—10.20	70.2
50 ck	82.5				78.2	89 ck	71.3				78.2	188 ck	64.7				78.2
51	85.3	82.5	+ 2.8	+ 3.39	80.8	88	67.0	71.3	— 4.3	— 6.03	73.5	189	70.3	64.7	+ 5.6	+ 8.66	85.0
52	83.9	83.4	+ 0.5	+ 0.60	78.7	87	67.0	80.2	—13.2	—16.46	65.3	190	68.4	75.9	— 7.5	— 9.88	70.5
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	83.4	— 1.8	— 2.16	76.5	85	70.3	80.2	— 9.9	—12.34	68.6	192	79.2	75.9	+ 3.3	+ 4.35	81.6
55	75.0	75.0	0.0	0.0	78.2	84	77.3	73.6	+ 3.7	+ 5.03	82.1	193	69.4	73.1	— 3.7	— 5.06	74.2
56 ck	75.0				78.2	83 ck	73.6				78.2	194 ck	73.1				78.2
57	83.4	75.0	+ 8.4	+11.20	87.0	82	81.1	73.6	+ 7.5	+10.19	86.2	195	67.0	73.1	— 6.1	— 8.34	71.7
58	85.3	76.4	+ 8.9	+11.65	87.3	81	73.6	75.0	— 1.4	— 1.87	76.7	196	82.5	71.3	+11.2	+15.71	90.5
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	76.4	— 7.0	— 9.16	71.0	79	78.8	75.0	+ 3.8	+ 5.07	82.2	198	71.3	71.3			78.2
61	81.6	78.3	+ 3.3	+ 4.21	81.5	78	79.2	81.1	— 1.9	— 2.34	76.4	199	56.7	57.7	— 1.0	— 1.73	76.8
62 ck	78.3				78.2	77 ck	81.1				78.2	200 ck	57.7				78.2
63	79.7	78.3	+ 1.4	+ 1.79	79.6	76	92.8	81.1	+11.7	+14.43	89.5	201	63.8	57.7	+ 6.1	+10.57	86.5
64	80.6	79.2	+ 1.4	+ 1.77	79.6	75	79.2	84.8	— 5.6	— 6.60	73.0	202	66.6	70.3	— 3.7	— 5.26	74.1
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	79.2	— 2.3	— 2.90	75.9	73	82.5	84.8	— 2.3	— 2.71	76.1	204	68.4	70.3	— 1.9	— 2.70	76.1
67	76.9	83.0	— 6.1	— 7.35	72.5	72	88.1	85.3	+ 2.8	+ 3.28	80.8	205	79.8	78.8	+ 1.0	+ 1.27	79.2
68 ck	83.0				78.2	71 ck	85.3				78.2	206 ck	78.8				78.2
69	73.6	83.0	— 9.4	—11.32	69.3	70	78.8	85.3	— 6.5	— 7.62	72.2	207	75.0	78.8	— 3.8	— 4.82	74.4

*The plats are arranged in this table in the same relative position as they occurred in the field.

TABLE 29—*Two hundred and seven thirtieth-acre Kherson oats plats calculated to show the progressive method of correction of yields by check plats where several plats intervene between checks*

Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield	Plat No.	Yield per acre		Deviation from normal		Corrected yield
	Actual	Normal					Actual	Normal					Actual	Normal			
	Bus.	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*		*Bus.*	*Bus.*	*Bushels*	*Per cent*	*Bushels*
1	75.5					138	87.2					139	81.6				
2 ck	84.8				78.2	137 ck	89.1				78.2	140 ck	83.0				78.2
3	86.3	84.8	+ 1.5	+ 1.77	79.6	136	84.8	88.4	— 3.6	— 4.07	75.0	141	83.9	81.1	+ 2.8	+ 3.45	80.9
4	84.4	84.8	— 0.4	— 0.47	77.8	135	84.4	87.8	— 3.4	— 3.87	75.2	142	75.5	79.2	— 3.7	— 4.67	74.5
5 ck	84.8				78.2	134 ck	87.2				78.2	143 ck	77.3				78.2
6	85.3	84.8	+ 0.5	+ 0.59	78.7	133	82.0	85.4	— 3.4	— 3.98	75.1	144	76.9	78.9	— 2.0	— 2.53	76.2
7	81.6	84.8	— 3.2	— 3.77	75.3	132	85.3	83.7	+ 1.6	+ 1.91	79.7	145	76.9	80.5	— 3.6	— 4.47	74.7
8 ck	84.8				78.2	131 ck	82.0				78.2	146 ck	82.0				78.2
9	80.2	83.0	— 2.8	— 3.37	75.6	130	77.3	81.4	— 4.1	— 5.04	74.3	147	75.0	79.9	— 4.4	— 5.51	73.9
10	79.7	81.1	— 1.4	— 1.73	76.9	129	79.8	80.8	— 1.0	— 1.24	77.2	148	75.5	77.7	— 2.2	— 2.83	76.0
11 ck	79.2				78.2	128 ck	80.2				78.2	149 ck	75.5				78.2
12	83.0	81.6	+ 1.4	+ 1.72	79.5	127	82.2	77.0	+ 5.2	+ 6.75	83.5	150	74.1	74.3	— 0.2	— .27	78.0
13	80.2	84.0	— 3.8	— 4.52	74.7	126	64.7	73.9	— 9.2	—12.45	68.5	151	69.8	73.0	— 3.2	— 4.38	74.8
14 ck	86.3				78.2	125 ck	70.8				78.2	152 ck	71.7				78.2
15	81.1	82.7	— 1.6	— 1.93	76.7	124	79.2	72.4	+ 6.8	+ 9.39	85.5	153	77.8	72.0	+ 5.8	+ 8.06	84.5
16	77.8	79.1	— 1.3	— 1.64	76.9	123	77.8	74.0	+ 3.8	+ 5.14	82.2	154	75.9	72.3	+ 3.6	+ 4.98	82.1
17 ck	75.5				78.2	122 ck	75.5				78.2	155 ck	72.7				78.2
18	68.4	77.2	— 8.8	—11.40	69.3	121	88.1	79.9	+ 8.2	+10.26	86.2	156	73.1	74.7	— 1.6	— 2.14	76.5
19	78.8	78.9	— .1	— 0.13	78.1	120	87.7	84.3	+ 3.4	+ 4.03	81.3	157	75.0	76.7	— 1.7	— 2.22	76.5
20 ck	80.6				78.2	119 ck	88.6				78.2	158 ck	78.8				78.2
21	82.5	80.0	+ 2.5	+ 3.13	80.6	118	81.6	86.4	— 4.8	— 5.56	73.8	159	76.9	77.9	— 1.0	— 1.28	77.2
22	85.3	79.4	+ 5.9	+ 7.43	84.0	117	85.3	84.2	+ 1.1	+ 1.31	79.2	160	72.7	76.9	— 4.2	— 5.46	73.9
23 ck	78.8				78.2	116 ck	82.0				78.2	161 ck	75.9				78.2
24	80.2	81.1	— 0.9	— 1.11	77.3	115	75.0	84.4	— 9.4	—11.14	69.5	162	75.9	76.9	— 1.0	— 1.30	77.2
25	78.8	83.4	— 4.6	— 5.52	73.9	114	75.9	86.8	—10.9	—12.56	68.4	163	80.6	77.9	+ 2.7	+ 3.47	80.9
26 ck	85.8				78.2	113 ck	89.1				78.2	164 ck	78.8				78.2
27	64.7	82.9	—18.2	—21.96	61.0	112	84.4	88.7	— 4.3	— 4.85	74.4	165	75.9	76.3	— 0.4	— 0.52	77.8
28	88.1	79.9	+ 8.2	+10.26	86.2	111	86.3	88.4	— 2.1	— 2.38	76.3	166	75.5	73.8	+ 1.7	+ 2.30	80.0
29 ck	76.9				78.2	110 ck	88.1				78.2	167 ck	71.3				78.2
30	83.4	77.8	+ 5.6	+ 7.20	83.8	109	79.2	87.7	— 8.5	— 9.69	70.6	168	72.2	71.6	+ 0.6	+ 0.84	78.9
31	80.6	78.7	+ 1.9	+ 2.41	80.1	108	80.6	87.2	— 6.6	— 7.57	72.3	169	72.7	71.9	+ 0.8	+ 1.11	79.1
32 ck	79.7				78.2	107 ck	86.7				78.2	170 ck	72.2				78.2
33	83.4	80.6	+ 2.8	+ 3.47	80.9	106	81.6	85.0	— 3.4	— 4.00	75.1	171	77.3	74.4	+ 2.9	+ 3.90	81.3

34	81.1	81.5	— 0.4	— 0.49	77.8	105	82.0	83.3	— 1.3	— 1.56	77.0	172	78.3	76.6	+ 1.7	+ 2.22	79.9
35 ck	82.5				78.2	104 ck	81.6				78.2	173 ck	78.8				78.2
36	80.2	82.2	— 2.0	— 2.43	76.3	103	89.5	78.1	+11.4	+14.60	89.6	174	75.9	79.4	— 3.5	— 4.41	74.7
37	79.7	81.9	— 2.2	— 2.69	76.1	102	75.9	74.7	— 1.2	— 1.61	76.9	175	78.8	80.0	— 1.2	— 1.50	77.0
38 ck	81.6				78.2	101 ck	71.3				78.2	176 ck	80.6				78.2
39	83.4	83.3	+ 0.1	+ 0.12	78.3	100	73.6	70.5	+ 3.1	+ 4.40	81.6	177	70.8	79.9	— 9.1	—11.39	69.3
40	78.8	85.0	— 6.2	— 7.29	72.5	99	83.0	69.7	+13.3	+19.08	93.1	178	72.7	79.1	— 6.4	— 8.09	71.9
41 ck	86.7				78.2	98 ck	68.9				78.2	179 ck	78.3				78.2
42	82.5	84.0	— 1.5	— 1.79	76.8	97	73.6	71.6	+ 2.0	+ 2.79	80.4	180	77.3	76.9	+ 0.4	+ 0.52	78.6
43	85.8	81.4	+ 4.4	+ 5.41	82.4	96	84.4	74.3	+10.1	+13.59	88.8	181	81.6	75.5	+ 6.1	+ 8.09	84.5
44 ck	78.8				78.2	95 ck	76.9				78.2	182 ck	71.4				78.2
45	79.7	78.8	+ 0.9	+ 1.14	79.1	94	82.0	75.5	+ 6.5	+ 8.61	84.9	183	75.5	76.7	— 1.2	— 1.56	77.0
46	69.4	78.8	— 9.4	—11.93	68.9	93	71.7	74.1	— 2.4	— 3.24	75.7	184	72.7	79.3	— 6.6	— 8.32	71.7
47 ck	78.8				78.2	92 ck	72.7				78.2	185 ck	82.0				78.2
48	83.0	80.0	+ 3.0	+ 3.75	81.1	91	74.5	72.3	+ 2.3	+ 3.04	80.6	186	65.6	76.3	—10.7	—14.02	67.2
49	79.7	81.2	— 1.5	— 1.85	76.8	90	73.1	71.8	+ 1.3	+ 1.81	79.6	187	71.3	70.5	+ 0.8	+ 1.13	79.1
50 ck	82.5				78.2	89 ck	71.3				78.2	188 ck	64.7				78.2
51	85.3	82.8	+ 2.5	+ 3.02	80.6	88	67.0	74.3	— 7.3	— 9.82	70.5	189	70.3	68.4	+ 1.9	+ 2.78	80.4
52	83.9	83.1	+ 0.8	+ .96	78.9	87	67.0	77.3	—10.3	—13.32	67.8	190	68.4	72.1	— 3.7	— 5.13	74.2
53 ck	83.4				78.2	86 ck	80.2				78.2	191 ck	75.9				78.2
54	81.6	80.6	+ 1.0	+ 1.24	79.2	85	70.3	78.0	— 7.7	— 9.87	70.5	192	79.2	74.9	+ 4.3	+ 5.74	82.7
55	75.0	77.8	— 2.8	— 3.60	75.4	84	77.3	75.8	+ 1.5	+ 1.98	79.7	193	69.4	74.0	— 4.6	— 6.22	73.3
56 ck	75.0				78.2	83 ck	73.6				78.2	194 ck	73.1				78.2
57	83.4	75.5	+ 7.9	+10.46	86.4	82	81.1	74.1	+ 7.0	+ 9.45	85.6	195	67.0	72.5	— 5.5	— 7.59	72.3
58	85.3	76.0	+ 9.3	+12.24	87.8	81	73.6	74.6	— 1.0	— 1.34	77.2	196	82.5	71.9	+10.6	+14.74	89.7
59 ck	76.4				78.2	80 ck	75.0				78.2	197 ck	71.3				78.2
60	69.4	77.0	— 7.6	— 9.87	70.5	79	78.8	77.0	+ 1.8	+ 2.34	80.0	198	71.3	66.7	+ 4.6	+ 6.90	72.8
61	81.6	77.6	+ 4.0	+ 5.15	82.2	78	79.2	79.0	+ 0.2	+ 0.25	78.4	199	56.7	62.2	— 5.5	— 8.84	71.3
62 ck	78.3				78.2	77 ck	81.1				78.2	200 ck	57.7				78.2
63	79.7	78.6	+ 1.1	+ 1.40	79.3	76	92.8	82.3	+10.5	+12.76	88.2	201	63.8	61.9	+ 1.9	+ 3.07	80.6
64	80.6	78.9	+ 0.7	+ .89	78.9	75	79.2	83.5	— 4.3	— 5.15	74.2	202	66.6	66.1	+ .5	+ 0.76	78.8
65 ck	79.2				78.2	74 ck	84.8				78.2	203 ck	70.3				78.2
66	76.9	80.5	— 3.6	— 4.47	74.7	73	82.5	85.0	— 2.5	— 2.94	75.9	204	68.4	73.1	— 4.7	— 6.43	73.2
67	76.9	81.8	— 4.9	— 5.99	73.5	72	88.1	85.2	— 2.9	— 3.40	75.5	205	79.8	75.9	+ 3.9	+ 5.14	82.2
68 ck	83.0				78.2	71 ck	85.3				78.2	206 ck	78.8				78.2
69	73.6					70	78.8					207	75.0				

*The plats are arranged in this table in the same relative position as they occurred in the field.

The three foregoing tables (27-29) show the exact arrangement in which the 207 Kherson oats plats were grown in the field. Certain plats have been designated as check plats according to each of the above three methods, and the intervening plats have been treated as test plats. The test plats have been corrected in yield according to the check plats. If such correction had been effective, the coefficient of variability for the corrected yields would have been materially reduced below the coefficient of variability for the actual yields. On the contrary, however, the coefficients of variability were reduced less than 1 per cent, being 7.8 per cent for the actual yields and 7.0 per cent for the corrected yields, as an average for the three methods of correction.

Table 30 gives the coefficients of variability for the actual and corrected yields of the test plats indicated in Tables 27, 28, and 29.

TABLE 30—*Effect upon yield from correcting thirtieth-acre Kherson oats field plats according to various accepted means of check plat correction* (1916)*

Arrangement of check plats used for correction	Frequency	Intervening plat yields		Standard deviation from mean for		Coefficient of variability for	
		Actual yields	Corrected yields	Actual yields	Corrected yields	Actual yields	Corrected yields
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*	*Per cent*
Alternate check plats. Correction based upon average of two adjacent checks	102	78.2	78.1	6.14	5.47	7.85	7.01
Checks every third plat. Correction based upon one adjacent check plat	138	78.0	77.7	6.08	5.71	7.79	7.35
Checks every third plat. Correction by progressive method based upon two nearest checks	132	78.0	77.7	6.13	5.10	7.87	6.57

*Calculated from data in Tables 27, 28, and 29.

REDUCTION OF ERROR BY REPLICATION

The actual yields from the first 200 of these similarly treated plats of Kherson oats, described on pages 52 to 60, have been compiled to show the extreme variations, average and standard deviations from the mean, and the coefficients of variability for single plats and for the mean yields of two, four, and eight plats averaged together. These groupings have been arranged for both adjacent and systematically distributed plats. The results are given in Table 31.

It is clearly shown that replication greatly reduces the extreme variation and coefficient of variability in the yield of field plats. A given number of replications are also much more effective when systematically distributed than when adjacent plats are averaged.

Fig. 15—Harvesting thirtieth-acre plats of Kherson oats. The binder has a gasoline engine attached which cuts and binds the grain. This facilitates cleaning out the binder quickly at the end of each plat. Note the narrow bare spaces between plats. If the plats are tangled by lodging, they are separated by hand before being cut. This shape of plat is very convenient, since it is one drill in width and may be harvested by one swath of the binder

TABLE 31—*Variation in yield of two hundred thirtieth-acre Kherson oats test plats when grouped in various numbers of systematically distributed or adjacent plats (1916)*

Classification	Number of groups	Mean yield per acre	Extreme variation	Average deviation	Standard deviation	Coefficient of variability
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*
GROUP COMPOSED OF SYSTEMATICALLY DISTRIBUTED PLATS						
Two hundred single plats	a 25	80.96	68.4—86.3	3.10	4.03	4.97
	b 25	80.67	64.7—88.1	3.29	4.87	6.04
	25	80.29	69.4—88.1	3.60	4.34	5.41
	d 25	76.10	67.0—92.8	4.77	5.86	7.71
	e 25	81.80	70.8—89.5	4.54	5.49	6.72
	f 25	80.10	64.7—89.1	4.24	5.25	6.55
	g 25	75.40	69.8—80.6	2.43	2.86	3.79
	h 25	72.40	56.7—82.5	5.15	6.66	9.21
Average		78.5	66.4—87.1	3.44	4.92	6.30
Every 100th plat, two plats in a group	a 25	81.4	73.4—87.9	2.82	3.44	4.23
	b 25	80.4	73.5—85.3	2.79	3.19	3.96
	c 25	77.9	71.1—83.2	2.38	2.94	3.77
	d 25	74.3	65.7—86.7	3.75	4.77	6.41
Average		78.5	70.9—85.8	2.93	3.58	4.59
Every 50th plat, four plats in a group	a 25	79.6	75.5—84.3	1.83	2.20	2.76
	b 25	77.3	72.0—81.0	2.04	2.37	3.06
Average		78.5	73.8—82.7	1.99	2.28	2.91
Every 25th plat, eight plats in a group	25	78.5	74.4—82.2	1.24	1.67	2.13

TABLE 31–(*Continued*)–*Variation in yield of two hundred thirtieth-acre Kherson oats test plats when grouped in various numbers of systematically distributed and adjacent plats (1916)*

Classification	Number of groups	Mean yield per acre	Extreme variation	Average deviation	Standard deviation	Coefficient of variability
		Bushels	*Bushels*	*Bushels*	*Bushels*	*Per cent*
GROUP COMPOSED OF ADJACENT PLATS						
Four adjacent plats in a group	a 25	80.8	72.0—85.4	2.10	2.99	3.71
	b 25	78.2	67.0—86.7	3.89	4.79	6.13
	c 25	81.0	67.8—88.2	3.70	4.65	5.74
	d 25	73.9	57.2—79.7	3.38	4.27	6.26
Average	....	78.5	66.0—85.0	3.26	4.18	5.46
Two adjacent plats in a group	a 25	79.5	72.9—84.8	2.60	3.30	4.15
	b 25	77.4	64.3—85.8	3.98	4.96	6.41
Average	....	78.5	68.6—85.3	3.29	4.13	5.28
Eight adjacent plats in a group	25	78.5	68.6—83.6	3.16	3.75	4.78
207 PLATS GROUPED TO MAKE PLATS OF VARIOUS SHAPES AND SIZES						
Three plats grouped lengthwise to make a plat	a 23	79.8	71.6—85.6	2.52	3.20	4.01
	b 23	78.9	71.3—84.6	2.17	2.90	3.67
	c 23	76.1	72.4—82.4	2.50	2.93	3.85
Average	....	78.3	71.8—84.2	2.40	3.01	3.84
Three plats grouped sidewise to make a plat	a 23	80.4	73.9—84.8	2.14	2.59	3.22
	b 23	79.9	70.5—86.0	4.31	4.96	6.21
	c 23	74.4	59.4—82.8	3.13	4.54	6.11
Average	....	78.2	67.9—84.5	3.19	4.03	5.18
Nine plats grouped lengthwise (3x3 plats) to make a plat*	a 23	78.2	73.8—84.0	2.27	2.62	3.35
Nine plats grouped sidewise (1x9 plats) to make a plat	a 23	78.2	68.6—83.1	3.23	3.78	4.84

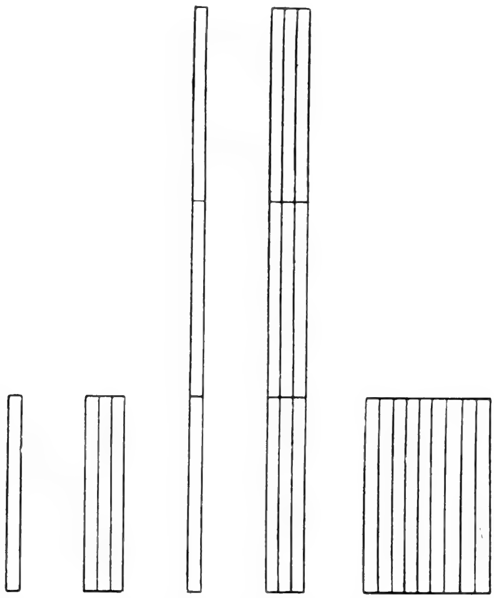
*In this grouping the combined plat was three plats long and three plats wide.

The yield of the 200 individual plats varied from 56.7 to 92.8 bushels per acre. The mean for eight groups of 25 single plats each gives an extreme difference between single plats of 20.7 bushels per acre. When two, four, and eight systematically distributed plats are averaged, the extreme differences in yield are respectively 14.9, 8.9, and 7.8 bushels. When two, four, and eight adjacent plats are averaged, these extreme differences are 19, 16.7, and 15 bushels. For systematically distributed plats the coefficients of variability for one, two, four, and eight plats in a group are 6.30, 4.59, 2.91, and 2.13 per cent. For adjacent plats the coefficients of variability for one, two, four, and eight plats in a group are 6.30, 5.46, 5.28, and 4.78 per cent.

Systematic distribution of replicated plats is seen to be very effective in reducing experimental error due to environmental variations.

EFFECT OF SHAPE AND SIZE OF PLAT

The 207 thirtieth-acre Kherson oats plats described in the preceding discussion were grouped to enable a compari-



Various ways of combining plats to make plats of different sizes and shapes (Table 31)

son of long narrow plats with short wide plats. The groupings illustrated in the following diagrams were compared. (In the 1 x 9 grouping, three groups were necessarily irregular in shape since 9 is not a multiple of 69.)

The results are included in Table 31. Long, narrow plats are indicated to be more reliable than short wide plats of the same area. Increasing the size of the plat is less effective in overcoming experimental error than the systematic distribution of plats equal in combined area.

SIGNIFICANCE OF THE "PROBABLE ERROR"

The "probable error" calculation is being used somewhat by field crop experimenters. Its use is rather inviting since a small "probable error" is customarily regarded as indicating accuracy in the results. Davenport's interpretation is generally accepted, namely: "It (the probable error) indicates the degree of confidence which we should place in results obtained by statistical methods."

Where plats are replicated two or more times, the probable error of the mean is based upon the standard deviation, and is determined by the following formula:

$$\text{Probable error of mean} = \pm\, 0.6745 \frac{\text{standard deviation}}{\sqrt{\text{number of variates}}}$$

which is also stated $E_m = \pm\, 0.6745 \frac{\sigma}{\sqrt{n}}$

The probable error is regarded as an upper and lower limit of divergence for which the chance is even that the true mean does not lie outside of these limits. Commenting upon the likelihood of the true mean lying outside of the limits set by the probable error, Davenport (1907) states:

"Of course the error in a determination has also an even chance of lying outside the limits set by the probable error (E), but the following table will show that it is very unlikely that the error is many times as great as E. Thus the chances that the true value lies within the range set by $\pm$ E, $\pm$ 2E, etc., are as follows:

$\pm$ E the chances are even
± 2 E the chances are 4.5 to 1
± 3 E the chances are 21 to 1
± 4 E the chances are 142 to 1
± 5 E the chances are 1310 to 1
± 6 E the chances are 19,200 to 1
± 7 E the chances are 420,000 to 1
± 8 E the chances are 17,000,000 to 1
± 9 E the chances are about 1,000,000,000 to 1

"It is extremely improbable, therefore, that an error will be many times as large as the probable error. For instance, it is practically certain that the error is not as large as 9 E, since the table shows that the chances are about a billion to one in favor of its being smaller than 9 E.

"Thus by giving, along with any result, the calculated probable error, the reader may know what degree of confidence is to be placed in the results."

In common usage, it is stated that the actual difference in the yield of two plats must be three times the probable error before the difference in yield is significant.

It should be agreed at the outset that the probable error of a mean yield has significance only when the variations entering into the mean are purely accidental rather than systematic. This distinction is understood by biometricians who universally attach importance to the probable error calculation when used in a legitimate manner. There appear to be strong possibilities of misusing the probable error and overestimating its value in agronomic studies. This need not be regarded as any defect in the probable error formula, but rather as a misapplication thereof to experimental results possessing either visible or invisible systematic errors.

Field crop investigators consider it good technique to replicate test plats. It has been proposed that, in such tests, small probable errors for the mean yields of the various varieties or treatments would indicate reliability and justify confidence in the comparative yields.

For the purpose of studying the significance of the probable error in field crop tests, the first 200 consecutive thirtieth-acre Kherson oats plats described on pp. 52 to 64 have been grouped in 50 sets of four adjacent plats and also 50 sets of four systematically distributed plats, and the probable error calculated for the mean yield of each group of four plats.

PROBABLE ERROR FOR FIFTY GROUPS OF FOUR ADJACENT THIRTIETH-ACRE PLATS OF KHERSON OATS

That the probable error cannot apply to the mean yields of adjacent duplicate plats in a variety test is brought out by the following data:

In Table 32 are given the mean yields for 50 groups of four adjacent plats, together with the average deviation, standard deviation, and probable error for each group. The average deviation of each group from the mean yield for the entire 200 plats is also indicated and in the last column of the table is given the ratio of this deviation to the probable error.

If it is permissible to assume that one group of four duplicate plats is comparable with another group of four plats in the same field, then it would also seem permissible to assume that in the present instances, the mean yield for the entire 200 similarly treated oats plats should represent the correct yield or true value of any or all of the individual groups within the field. If this assumption be made with the adjacent duplicate plats (Table 32), the actual error of these group means exceeded their probable error approximately 0, 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, and 15 times respectively in 9, 5, 7, 7, 8, 4, 4, 1, 2, 1, 1, and 1 groups. (See Col. 11, Table 32). This is very inconsistent with the table of probabilities quoted from Davenport on page 66, and shows that a uniform appearing field may be so heterogeneous in soil conditions that its mean yield cannot be regarded as correctly representing the true value of its various parts.

Since all the plats were treated and planted alike any difference in the yields of the groups represents experimental error, either in mechanical operations or in soil variation.

Among the 50 groups of adjacent plats, one group yielded 14.2 bushels less and another group 7.3 bushels more per acre than the 200-plat mean. These extremes represent an experimental error of 21.5 bushels since both should have yielded alike if the method of comparison were reliable.

Should we presume that groups No. 30 and No. 50 (Table 32) are distinct varieties in a comparative variety test, we would have a difference in yield of 21.5 bushels per acre. After multiplying the probable error of each mean by three, there remains a net difference of 11.63 bushels between the probable error ranges. Placing confidence in the probable error calculation, we would believe that there is a difference

TABLE 32—*Probable error for mean yields of four adjacent thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
1	75.5	84.8	86.3	84.4	82.8	3.600	4.246	±1.43	+ 4.3	3.01
2	84.8	85.3	81.6	84.8	84.1	1.275	1.472	± .50	+ 5.6	11.20
3	80.2	79.7	79.2	83.0	80.5	1.225	1.555	± .52	+ 2.0	3.85
4	80.2	86.3	81.1	77.8	81.4	2.500	3.102	±1.05	+ 2.9	2.76
5	75.5	68.4	78.8	80.6	75.8	3.875	4.661	±1.57	— 2.7	1.72
6	82.5	85.3	78.8	80.2	81.7	2.200	2.463	± .83	+ 3.2	3.86
7	78.8	85.8	64.7	88.1	79.4	7.600	9.126	±3.08	+ 0.9	0.29
8	76.9	83.4	80.6	79.7	80.2	1.850	2.321	± .78	+ 1.7	2.18
9	83.4	81.1	82.5	80.2	81.8	1.150	1.235	± .51	+ 3.3	6.47
10	79.7	81.6	83.4	78.8	80.9	1.625	1.774	± .60	+ 2.4	4.00
11	86.7	82.5	85.8	78.8	83.5	2.800	3.107	±1.05	+ 5.0	4.76
12	79.7	69.4	78.8	83.0	77.7	4.175	5.054	±1.70	— 0.8	0.47
13	79.7	82.5	85.3	83.9	82.9	1.750	2.071	± .70	+ 4.4	6.29
14	83.4	81.6	75.0	75.0	78.8	3.750	3.804	±1.28	+ 0.3	0.23
15	83.4	85.3	76.4	69.4	78.6	5.725	6.273	±2.12	+ 0.1	0.05
16	81.6	78.3	79.7	80.6	80.1	1.050	1.215	± .41	+ 1.6	3.90
17	79.2	76.9	76.9	83.0	79.0	2.100	2.493	± .84	+ 0.5	0.60
18	73.6	78.8	85.3	88.1	81.5	5.250	5.650	±1.91	+ 3.0	1.57
19	82.5	84.8	79.2	92.8	84.8	3.975	5.016	±1.69	+ 6.3	3.73
20	81.1	79.2	78.8	75.0	78.5	1.775	2.213	± .75	....	....
21	73.6	81.1	73.6	77.3	76.4	2.800	3.106	±1.05	— 2.1	2.00
22	70.3	80.2	67.0	67.0	71.1	4.525	5.410	±1.82	— 7.4	4.07
23	71.3	73.1	74.5	72.7	72.9	.900	1.140	± .38	— 5.6	14.73
24	71.7	82.0	76.9	84.4	78.8	4.450	4.890	±1.65	+ 0.3	0.18
25	73.6	68.9	83.0	73.6	74.8	4.125	5.122	±1.73	— 3.7	2.14

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 32—*(Continued)—Probable error for mean yields of four adjacent thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
26	71.3	75.9	89.5	81.6	79.6	5.975	6.793	±2.29	+ 1.1	0.48
27	82.0	81.6	86.7	80.6	82.7	1.975	2.351	± .79	+ 4.2	5.32
28	79.2	88.1	86.3	84.4	84.5	2.700	3.328	±1.12	+ 6.0	5.36
29	89.1	75.9	75.0	82.0	80.5	5.050	5.648	±1.90	+ 2.0	1.05
30	85.3	81.6	88.6	87.7	85.8	2.350	2.710	± .91	+ 7.3	8.02
31	88.1	75.5	77.8	79.2	80.2	4.000	4.777	±1.61	+ 1.7	1.06
32	70.8	64.7	82.2	80.2	74.5	6.725	7.098	±2.39	— 4.0	1.67
33	79.8	77.3	82.0	85.3	81.1	2.550	2.940	± .99	+ 2.6	2.63
34	82.0	87.2	84.4	84.8	84.6	1.400	1.844	± .62	+ 6.1	9.84
35	89.1	87.2	81.6	83.0	85.2	2.925	3.042	±1.03	+ 6.7	6.50
36	83.9	75.5	77.3	76.9	78.4	2.750	3.245	±1.09	— 0.1	0.09
37	76.9	82.0	75.0	75.5	77.4	2.350	2.774	± .94	— 1.1	1.17
38	75.5	74.1	69.8	71.7	72.8	2.025	2.190	± .74	— 5.7	7.70
39	77.8	75.9	72.7	73.1	74.9	1.975	2.091	± .70	— 3.6	5.14
40	75.0	78.8	76.9	72.7	75.9	2.000	2.262	± .76	— 2.6	3.42
41	75.9	75.9	80.6	78.8	77.8	1.900	2.004	± .68	— 0.7	1.03
42	75.9	75.5	71.3	72.2	73.7	1.975	2.006	± .68	— 4.8	7.06
43	72.7	72.2	77.3	78.3	75.1	2.675	2.704	± .91	— 3.4	3.74
44	78.8	75.9	78.8	80.6	78.6	1.275	1.686	± .57	+ 0.1	0.18
45	70.8	72.7	78.3	77.3	74.8	3.025	3.119	±1.05	— 3.7	3.52
46	81.6	74.1	75.5	72.7	76.0	2.825	3.395	±1.14	— 2.5	2.19
47	82.0	65.6	71.3	64.7	70.9	5.750	6.890	±2.32	— 7.6	3.28
48	70.3	68.4	75.9	79.2	73.5	4.100	4.316	±1.46	— 5.0	3.42
49	69.4	73.1	67.0	82.5	73.0	4.800	5.900	±1.99	— 5.5	2.76
50	71.3	71.3	56.7	57.7	64.3	7.050	7.059	±2.38	—14.2	5.97

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 33—*Probable error for mean yields of four systematically distributed thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
1	75.5	85.3	71.3	69.8	75.5	4.925	6.045	±2.04	—3.0	1.47
2	84.8	83.9	75.9	71.7	79.1	5.275	5.490	±1.85	+0.6	0.32
3	86.3	83.4	89.5	77.8	84.3	3.650	4.304	±1.45	+5.8	4.00
4	84.4	81.6	81.6	75.9	80.9	2.475	3.091	±1.04	+2.4	2.31
5	84.8	75.0	82.0	72.7	78.6	4.775	4.944	±1.67	+0.1	0.06
6	85.3	75.0	81.6	73.1	78.8	4.700	4.925	±1.66	+0.3	0.18
7	81.6	83.4	86.7	75.0	81.7	3.375	4.266	±1.44	+3.2	2.22
8	84.8	85.3	80.6	78.8	82.4	2.675	2.756	± .93	+3.9	4.19
9	80.2	76.4	79.2	76.9	78.2	1.525	1.576	± .53	—0.3	0.57
10	79.7	69.4	88.1	72.7	77.5	6.425	7.174	±2.42	—1.0	0.41
11	79.2	81.6	86.3	75.9	80.8	3.200	3.790	±1.28	+2.3	1.80
12	83.0	78.3	84.4	75.9	80.4	3.300	3.443	±1.16	+1.9	1.64
13	80.2	79.7	89.1	80.6	82.4	3.350	3.881	±1.31	+3.9	2.98
14	86.3	80.6	75.9	78.8	80.4	3.050	3.797	±1.28	+1.9	1.48
15	81.1	79.2	75.0	75.9	77.8	2.350	2.465	± .83	—0.7	0.84
16	77.8	76.9	82.0	75.5	78.1	2.000	2.424	± .82	—0.4	0.49
17	75.5	76.9	85.3	71.3	77.3	4.050	5.084	±1.71	—1.2	0.70
18	68.4	83.0	81.6	72.2	76.3	6.000	6.168	±2.08	—2.2	1.06
19	78.8	73.6	88.6	72.7	78.4	5.275	6.319	±2.13	—0.1	0.05
20	80.6	78.8	87.7	72.2	79.8	4.325	5.518	±1.86	+1.3	0.70
21	82.5	85.3	88.1	77.3	83.3	3.400	3.990	±1.35	+4.8	3.56
22	85.3	88.1	75.5	78.3	81.8	4.900	5.096	±1.72	+3.3	1.92
23	78.8	82.5	77.8	78.8	79.5	1.525	1.794	± .61	+1.0	1.64
24	80.2	84.8	79.2	75.9	80.0	2.475	3.183	±1.07	+1.5	1.40
25	78.8	79.2	70.8	78.8	76.9	3.050	3.526	±1.19	—1.6	1.34

*The field mean equals the mean for the entire 200 plats reported in this table.

TABLE 33—*(Continued)—Probable error for mean yields of four systematically distributed thirtieth-acre Kherson oats plats when 200 plats are arranged in 50 groups (1916)*

Group No.	Yield per acre for four plats averaged				Mean yield per acre	Average deviation	Standard deviation	Probable error of mean	Deviation of group mean from field mean*	Ratio of Col. 10 to Col. 9
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	
26	85.8	92.8	64.7	80.6	81.0	8.325	10.364	±2.49	+2.5	1.00
27	64.7	81.1	82.2	70.8	74.7	6.950	7.287	±2.46	—3.8	1.54
28	88.1	79.2	80.2	72.7	80.1	4.100	5.468	±1.84	+1.6	0.87
29	76.9	78.8	79.8	78.3	78.5	.850	1.046	± .35	....	....
30	83.4	75.0	77.3	77.3	78.3	2.600	3.118	±1.05	—0.2	0.19
31	80.6	73.6	82.0	81.6	79.5	2.900	3.146	±1.15	+1.0	0.87
32	79.7	81.1	85.3	74.1	80.1	3.150	4.006	±1.35	+1.6	1.19
33	83.4	73.6	82.0	75.5	78.6	4.075	4.160	±1.40	+0.1	0.07
34	81.1	77.3	87.2	72.7	79.6	4.575	5.313	±1.79	+1.1	0.62
35	82.5	70.3	84.4	82.0	79.8	4.750	5.557	±1.87	+1.3	0.70
36	80.2	80.2	84.8	65.6	77.7	6.050	7.234	±2.44	—0.8	0.33
37	79.7	67.0	89.1	71.3	76.8	7.625	8.455	±2.85	—1.7	0.60
38	81.6	67.0	87.2	64.7	75.1	9.275	9.519	±3.21	—3.4	1.06
39	83.4	71.3	81.6	70.3	76.7	5.850	5.895	±1.99	—1.8	0.90
40	78.8	73.1	83.0	68.4	75.8	5.075	5.542	±1.87	—2.7	1.44
41	86.7	74.5	83.9	75.9	80.3	5.050	5.170	±1.74	+1.8	1.03
42	82.5	72.7	75.5	79.2	77.5	3.375	3.706	±1.25	—1.0	0.80
43	85.8	71.7	77.3	69.4	76.1	5.500	6.320	±2.13	—2.4	1.05
44	78.8	82.0	76.9	73.1	77.7	2.700	3.221	±1.09	—0.8	0.73
45	79.7	76.9	76.9	67.0	75.1	4.075	4.828	±1.63	—3.4	2.09
46	69.4	84.4	82.0	82.5	79.6	5.075	5.942	±2.00	+1.1	0.55
47	78.8	73.6	75.0	71.3	74.7	2.225	2.724	± .92	—3.8	4.13
48	83.0	68.9	75.5	71.3	74.7	4.575	5.356	±1.81	—3.8	2.10
49	79.7	83.0	75.5	56.7	73.7	8.525	10.183	±3.43	—4.8	1.40
50	82.5	73.6	74.1	57.7	72.0	7.125	8.968	±3.02	—6.5	2.15

*The field mean equals the mean for the entire 200 plats in this table.

of 11.63 bushels in the true value of the two varieties. However, we know in this case that both groups should have yielded alike since they were planted to the same crop. The probable error would give us confidence in very inaccurate results.

Slightly different results are obtained when the above example is calculated by the following prescribed formula: "The probable error of the difference of two means each affected with a probable error, is equal to the square root of the sum of the squares of the probable errors." By this formula the difference in mean yield of groups Nos. 30 and 50 equals 21.5 ± 2.55 bushels. Three times the probable error is 7.65 bushels which leaves a net difference of 13.85 bushels.

PROBABLE ERROR OF FIFTY GROUPS OF FOUR SYSTEMATICALLY DISTRIBUTED THIRTIETH-ACRE PLATS OF KHERSON OATS

Table 33 contains results with the same 200 Kherson Oats plats as compiled in Table 32, except that systematically distributed plats rather than adjacent plats are averaged in groups of four each. If the mean yield of the entire 200 plats is here regarded as the true value of the various group means, the actual error of these group means exceeded their probable error 0, 1, 2, 3, and 4 times in 10, 25, 10, 1, and 4 groups (See Col 11). This is a marked reduction in actual error as compared with similar data for adjacent plats and indicates a great advantage for systematic distribution. An application of the probable error to these systematically distributed plats would seem fairly reasonable altho it cannot be applied absolutely.

Because of chance groupings of either large or small variations where relatively small numbers are used, the actual error of a mean may be greater than three times its probable error, or it may be smaller than the probable error. Data may be either more or less accurate than an application of the probable error would indicate.

EXAMPLES OF LIMITATION OF THE PROBABLE ERROR

Small Grain Row Tests—In Tables 1 to 7 were given the relative small grain yields of rate-of-planting or variety tests in alternating nursery rows. The plats were replicated 50 times and the probable error of the mean yields is indicated. The yields in these plats were subject to two sources of error, namely soil variation and plat competition. Corresponding

tests were also made in five-row plats relatively free from plat competition and subject primarily only to soil variations.

In Table 1 (1913) the yields of the thick and thin planted wheat rows were, respectively, 389±5.3 and 264±3.8 grams. Altho the probable error for each yield is less than 2 per cent, the actual error of the relative yields due to competition is 24.4 per cent. In 1914 the yields of the thick and thin planted wheat rows were respectively 327±6.66 and 115±3.6 grams. Altho the probable error for each yield is only 2 per cent, the actual error of the relative yields, due to competition, is 56.8 per cent.

In 1913 (Table 2) the probable errors for the mean yields of thick and thin planted oats rows were less than 2 per cent, but the actual error in relative yields, due to competition, was 20 per cent. In 1914 the probable errors for similar yields were also below 2 per cent, while the actual error in relative yields, due to competition, was 34.3 per cent.

Similar examples are seen in variety tests in Tables 3 to 7. We would have great confidence in these single-row tests were we to judge them by their low "probable errors." However, it is evident that this confidence would be badly misplaced.

Crop tests are subject to such a multitude of local environmental influences that errors in them cannot be regarded as occurring according to the formulas or rules of chance calculated from purely mechanical observations. The probable error calculation may apply, for example, to the chance drawing of black and white marbles from a bag at a given ratio to each other. But variations in crop yields are no such simple matter, and the probable error not only may have little significance but may be misleading.

Water Requirements of Corn and Wheat—As further illustration of the limitation of the probable error, the following simple data from our 1916 water requirements of crop studies may be cited.

The object was to make a comparative test of the relative water requirements for grain production of a standard variety of both corn and winter wheat. Potometers, 16 by 36 inches in size and containing 250 pounds of well-manured moisture-free soil, were used. (The method of testing is described in detail in Nebraska Research Bulletin No. 6.)

Previous experiments had indicated that these potometers would grow one corn plant in a normal manner. The ratio

of 100 seeds of wheat to one of corn is normal in planting under field conditions in this region. Accordingly in comparing corn and wheat in potometers they were planted respectively at the rates of one plant and 100 plants per pot.

Under these conditions the respective water requirements for grain production of the corn and wheat were 743 ± 48 and 1017 ± 60. However, when the corn was grown at the rate of six plants per potometer these relative water requirements were 3481 ± 389 and 1017 ± 60.

Applying the general rule of "three times the probable error," we may be fairly confident from the one comparison that Hogue's Yellow Dent corn uses considerably less water than Turkey Red winter wheat, and from the other comparison we may be equally confident that corn uses more than double the amount of water for grain production than the wheat.

In the first comparison the degree of cropping for this quantity of soil corresponded well with normal field conditions for each crop. In the second test, however, the corn was planted relatively much too thick, and for this reason the ratio of grain to vegetative growth was greatly reduced. As a result the water requirement for grain production was increased.

EFFECT OF CHANGE IN METHODS ON AGRONOMIC EQUIPMENT

Replacing the single-row nursery test plat planted in duplicate with five-row test plats replicated 10 times increases the land requirement 25 times for such nursery testing. In testing hoed crops the substitution of three-row plats, replicated five times, for single duplicated rows requires 15 rows rather than two rows. The replication of small grain field plats five times, rather than twice, greatly increases the land requirement.

Fertilizer and tillage experiments which frequently are conducted in unduplicated plats should probably be at least triplicated. Reduction of error by replication is more effective than the use of check plats alone.

The introduction of check plats every fifth plat in itself occupies one-fifth of the land. The more refined methods of securing comparable stands of corn upon which to base the yields at harvest require much greater labor expenditure than formerly.

The proper conduct of experimental work in crop production in light of our present knowledge requires either a large extension in land area and labor facilities or else a marked restriction in the amount of investigation carried on.

MEASURING IMPROVEMENT IN YIELD THRU BREEDING

Comparing the yield of corn for one period of years with the yield of another period is an unreliable method for noting improvement thru corn breeding. An illustration of this method is found in a circular of the United States Department of Agriculture Office of Corn Investigations, August 20, 1914. The data in Table 34 were given in this circular as

TABLE 34—*Data given in Circular of Office of Corn Investigations, U. S. Department of Agriculture, August 20, 1914, to show improvement from ear-to-row breeding conducted at Piketon, Pike County, Ohio*

	Average for first seven years, 1901-1907 inclusive	Average for second seven years, 1907-1913 inclusive	Ratio first period to second period
	Bushels	*Bushels*	
Yield per acre as weighed in the fall (70 lbs. of ears to the bushel)	77	85	100:110.4
Yield per acre of dry shelled grain (56 lbs. to the bushel)	63	75	100:119

indicating 19 per cent increase in yield of dry shelled corn per acre by ear-to-row breeding. The increase in yield of ear corn as weighed at husking time was 10.4 per cent. The measure of improvement by breeding was the average increased yield during a seven year period, 1907-1913, over the previous seven-year period.

A comparison of the yields in Table 35 during these same two periods for the state of Ohio as compiled from the United States Yearbook indicates a similar increase in yield for the state in general. During the last period of seven years, the Ohio state yield was 11.4 per cent higher than during the previous seven years. Likewise data compiled from the reports of the Ohio State Secretary of Agriculture, indicate 9.4 per cent greater yield for Pike County, in which the experiments were conducted, during the last seven years than during the previous seven years. This suggests that more favor-

TABLE 35—*Ohio state and Pike County yields of corn averaged for the same periods as given in Circular of the office of Corn Investigations, August 20, 1914*

	Average for first seven years, 1901-1907 inclusive	Average for second seven years, 1907-1913 inclusive	Ratio first period to second period	Average yield for nine years previous to first period
	Bushels	*Bushels*		*Bushels*
Yield per acre for state of Ohio as compiled from U. S. Yearbook......	34.4	38.3	100:111.4	32.8
Yield per acre for Pike County, Ohio, as compiled from the reports of the Ohio State Board of Agriculture.....	28.7	31.4	100:109.4	

able climatic conditions may have been the cause of the apparent improvement of the ear-to-row corn.

A similar method of measuring improvement by ear-to-row corn breeding at the Nebraska Experiment Station during the same period of 13 years, gives the results shown in Table 36. The yield of continuous ear-to-row breeding strains during the seven-year period 1907-1913 was 61 per cent as great as during the preceding seven years. It would appear that the corn yield had been reduced 39 per cent by ear-to-row breeding during the last seven years. However, a comparison of yields in Lancaster County, in which the Station is located, shows a decreased yield of 30 per cent, and the State as a whole a decreased yield of 17.3 per cent for the same two periods. Further, the yield of the original unselected Hogue's Yellow Dent corn showed a decreased yield of 35 per cent at the Experiment Station during the second seven-year period. All indications are that the reduced yield of ear-to-row corn at the Experiment Station was due to climatic conditions and not to the breeding. An actual comparison of the ear-to-row corn during the last period of seven years with the original corn of the same variety planted each year as a check indicates an actual increased yield of 5.4 per cent due to breeding, whereas the other method of comparison indicated a decreased yield of 39 per cent.

TABLE 36—*Nebraska data compiled to show results secured by the Nebraska Experiment Station from ear-to-row breeding if compared by the method of the Office of Corn Investigations reported in Table 31*

	Average yield for first seven years, 1901-1907 inclusive	Average yield for second seven years, 1907-1913 inclusive	Ratio	Average yield for nine years previous to first period
	Bushels	*Bushels*		*Bushels*
Yield for State of Nebraska as compiled from U. S. Yearbook.............	28.3	23.4	100:82.7	24.1
Average yield for Lancaster County.	30.0	21.0	100:70	....
General crop of Hogue's Yellow Dent corn at the Nebraska Experiment Station..............	69.6	45.6	100:65.5	....
Yield per acre, at the Nebraska Experiment Station of Hogue's Yellow Dent corn which has undergone continuous ear-to-row breeding since 1902	81.5*	49.9	100:61.0	....
Yield per acre at the Nebraska Experiment Station of original unselected Hogue's Yellow Dent corn used as check for measuring improvement from breeding†...	....	47.2	....	....

*The yield for ordinary Hogue's Yellow Dent Corn for 1901 is included in this average.

†Averaging together these data for the seven years 1909-1915—during which period the precaution was taken to have strictly comparable results by thinning to a uniform stand and to reduce error by several replications—we have an average yield for the continuous ear-to-row breeding stock of 49.2 bushels, and the comparable check yield is 48.9 bushels.

A comparison of the Hogue's Yellow Dent ear-to-row-selection with the original unselected Hogue's Yellow Dent corn for the seven-year period 1909-1915—during which time the precaution was taken to have strictly comparable results by thinning to a uniform stand, and to reduce error by several replications—indicates an increased yield of only six-tenths of one per cent due to the breeding.

In order to measure progress in the improvement of corn thru breeding, it is necessary to compare the results each year with the original unselected corn.

SOIL LIMITATION AS A SOURCE OF ERROR IN POT EXPERIMENTS

The past discussions in this bulletin have dealt entirely with field experiments. Extensive use has also been made of pots filled with soil for comparing the yields of various crops and soil types, and for determining the fertilizer needs of different soils and the water requirement of crops. A review of the literature indicates a marked lack of uniformity in the size of pots and rate of planting in them.

Tables 37 to 47 contain the results from experiments conducted during three years, 1913-1915, bearing upon the effect of the size and rate of planting as sources of experimental error in pot tests.

Galvanized iron pots were used, having a constant water supply from jars connected at the bottom. Rain was excluded by means of a closefitting cover about the stalk, and surface evaporation was reduced by means of a three-inch layer of gravel. All pots were planted each year from the same ear of Hogue's Yellow Dent corn. Suckers were removed as soon

TABLE 37—*Summary showing the effect of the size of the pot upon the growth of corn. Hogue's Yellow Dent corn (1913)*

Size of pot	Wt. of soil (moisture-free)	No. of pots averaged	Dry matter		Total leaf-area per plant	Height of stalk
			Ear	Total		
Inches	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x24...	86	4	28	165	680	71
16x36...	245	80	194	416	1070	89
30x36...	933	4	311	599	1440	83

as they started, so as to prevent variability in the number of stalks per pot. Thus uniform conditions were provided thruout all pots except the one or two variable factors under observation. The pots were located in trenches within a cornfield, with their tops level with the field. They were filled with fertile surface soil from the Experiment Station Farm. The manure which was used in half of the pots during 1914 and 1915, as designated, was well-rotted sheep manure, and was thoroly mixed with the upper ten inches of soil.

TABLE 38—*Summary of data showing the effect of the size of pot upon grcw:h of corn. Hogue's Yellow Dent corn (1914)*

Size of pot	Moisture-free contents		No. of pots averaged	Dry matter		Total leaf-area per plant	Height of plant
	Soil	Manure		Ear	Total		
Inches	*Pounds*	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x12....	32.5		4	10	98	705	76
12x12....	32.5	1.75	4	82	269	1167	102
12x24....	85		4	63	206	1165	100
12x24....	85	1.75	4	186	402	1353	106
16x24....	150		4	108	316	1343	110
16x24....	150	1.75	4	270	535	1369	112
16x36....	239		3	242	442	1193	116
16x36....	239	1.75	8	287	558	1322	114
21x36....	583		4	299	628	1308	112
21x36....	583	1.75	4	341	708	1405	114
30x36....	956		3	405	728	1269	108
30x36....	956	1.75	4	416	781	1287	114

TABLE 39—*Showing in per cent the effect of increasing the size of pot. The results in the different sizes without manure are here expressed in per cent of the results in the smallest size without manure. Hogue's Yellow Dent corn (1914)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12...........	32.5	100.0	100.0	100.0	100.0
12x24...........	85.0	632.5	211.0	165.2	131.3
16x24...........	150.0	1082.3	324.1	190.6	144.7
16x36...........	239.0	2417.0	453.6	169.3	153.0
21x36...........	583.0	2990.0	643.8	185.6	147.4
30x36...........	956.0	4046.7	747.0	180.0	142.1

*Data calculated from Table 38.

EFFECT OF THE SIZE OF POT UPON THE GROWTH OF CORN

In 1913 individual plants of Hogue's Yellow Dent corn were grown in pots of three different sizes. The results are summarized in Table 37. In pots containing 86, 245, and 933 pounds of soil, the average total dry matter harvested per pot was respectively 165, 416, and 599 grams, while the average weights of ear corn were 28, 194, and 311 grams.

In 1914, six sizes of pots were used, which contained 32, 85, 150, 239, 583, and 956 pounds of moisture-free soil. Four pots of each size were cropped without manure and four with manure. The results are summarized in Table 38. Table 39 shows in percentage the effect upon yields of increasing the pot size. Using the crop harvested in the smallest pots without manure as 100 per cent, the yields of total dry matter for the other sizes without manure were respectively 211, 324.1, 453.6, 643.8, and 747 per cent. The yields of ear corn were respectively 100, 632.5, 1082.3, 2417, 2990, and 4046.7 per cent.

Table 40 shows in per cent the effect of applying a uniform rate of manure to the pots of different sizes in 1914. The yield with manure is expressed in per cent of the yield without manure for each size.

TABLE 40—*Showing in per cent the effect of applying a uniform rate of manure to pots of different sizes. The results with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1914)**

Size of pot	Wt. of soil (moisture-free)	Dry matter: Ear	Dry matter: Total	Total leaf-area per plant	Height of stalk
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Inches*
12x12	32.5	822.5	276.4	165.6	133.5
12x24	85.0	293.6	195.3	116.2	106.2
16x24	150.0	249 2	169 3	101.8	101.3
16x36	239.0	118.9	126.1	110.7	98.3
21x36	583.0	114.1	112.7	107.4	101.8
30x36	956.0	102.9	107.2	101.4	105.5

*Data calculated from Table 38.

Applying 1.75 pounds of moisture-free manure per pot increased the yields of total dry matter for the different sized pots respectively 176.4, 95.3, 69.3, 26.1, 12.7, and 7.2 per cent. Likewise, the manure increased the yields of grain per pot

1 2 3 4 5 6

Fig. 16—Representative plants of Hogue's Yellow Dent Corn grown one stalk per pot, in pots of different sizes, 1914. (Table 38) Each set contains a plant grown with and without manure. Pounds of soil per pot, left to right 1—32.5; 2—85; 3—150; 4—239; 5—583; 6—956

respectively 722.5, 193.6, 149.2, 18.9, 14.1, and 2.9 per cent, according to the size of the pot.

In the above experiment for 1914, the manure was applied on the individual plant basis. Assuming a normal stand of 3556 hills, each containing 3 plants, an acre of corn has 10,668 plants. One and seventy-five one hundredths pounds of moisture-free manure per plant would be at the rate of 9.33 tons per acre.

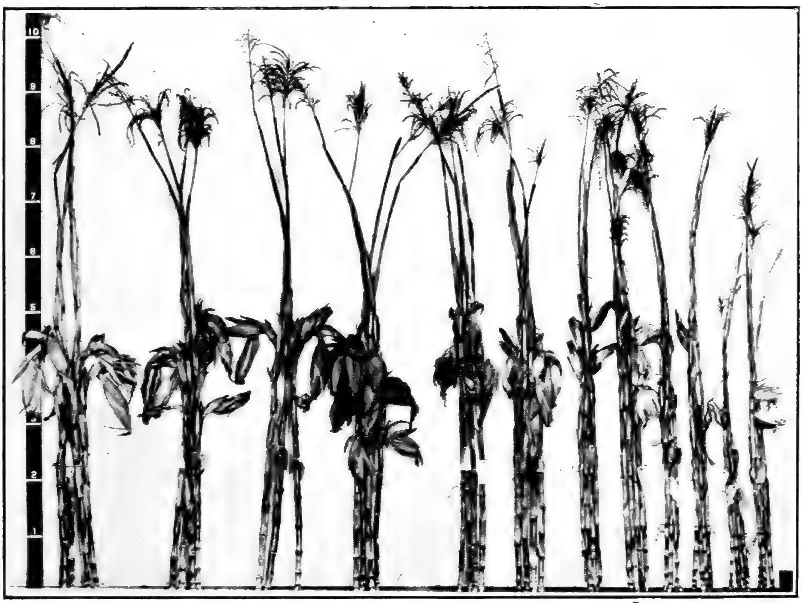
In 1915, the same six sizes of pots were used as in 1914, and contained respectively 36, 83, 161, 253, 561, and 920 pounds of moisture-free soil. There were eight pots of each size, four of which were manured. Table 41 contains a summary of the results. Table 42 shows in percentage the effect of increasing the pot size upon yield.

Based upon the yield in the smallest pots, without manure, the relative yields of dry matter for the respective sizes were 100, 150, 229.6, 355.6, 586, and 578.7 per cent. The relative yields of ear corn were respectively 100, 276.2, 819, 1,647.5, 2,771.3, and 2,667 per cent.

Table 43 shows in percentage the effects of applying, to the pots of different sizes, manure in amounts proportional

TABLE 41—*Summary of data showing the effect of the size of the pot upon the growth of corn. Hogue's Yellow Dent corn (1915)*

Size of pot	Moisture-free contents		No. of pots averaged	Dry matter		Total leaf-area per plant	Height of plant
	Soil	Manure		Ear	Total		
Inches	*Pounds*	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
12x12....	36		4	10.5	108	753	71
12x12....	36	.08	4	17.8	107	776	80
12x24....	83		4	29	162	1061	98
12x24....	83	.18	4	30	172	1219	102
16x24....	161		4	86	248	1150	109
16x24....	161	.36	4	76	273	1238	111
16x36....	253		4	173	384	1209	114
16x36....	253	.55	4	203	456	1266	111
24x36....	561		3	291	633	1323	120
24x36....	561	1.25	4	366	684	1372	116
30x36....	920		4	280	625	1226	116
30x36....	920	2.00	4	331	685	1307	112



1 2 3 4 5 6 7 8 9 10 1

Fig. 17—Crop harvested from pots of six different sizes, 1915 (Table 41). One plant was grown per pot, with four pots of each size. Odd numbers without manure, even numbers with manure. (Manure added in proportion to soil contents.)

Pounds of soil, left to right: 1 and 2—920 lbs.; 3 and 4—561 lbs.; 5 and 6—253 lbs.; 7 and 8—161 lbs.; 9 and 10—83 lbs.; 11 and 12—36 lbs.

to the amount of soil. Two pounds of moisture-free manure were applied to the largest pots, while the amounts added to the other sizes were respectively 1.25, 0.55, 0.36, 0.18, 0.8 pounds. Expressed in per cent of the yields without manure, the manured pots yielded 99.1, 106.2, 110.1, 118.8, 108, and 109.6 per cent total dry matter, and 169.5, 103.5, 88.4, 117.3, 125.7 and 118.2 per cent of ear corn.

TABLE 42—*Showing in per cent the effect of increasing the size of the pot. The results in the different sized pots without manure are here expressed in per cent of the results in the smallest pots without manure. Hogue's Yellow Dent corn (1915)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12	36	100.0	100.0	100.0	100.0
12x24	83	276.2	150.0	140.9	138.0
16x24	161	819.0	229.6	152.7	153.5
16x36	253	1647.5	355.6	160.6	160.6
21x36	561	2771.3	586.1	175.7	169.0
30x36	920	2667.0	578.7	162.8	163.4

*Data calculated from Table 41.

TABLE 43—*Summary of data showing the effect of applying manure proportional to the amount of soil in pots of different sizes. The results with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1915)**

Size of pot	Wt. of soil (moisture-free)	Dry matter		Total leaf-area per plant	Height of stalk
		Ear	Total		
Inches	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
12x12	36	169.5	99.1	103.1	112.7
12x24	83	103.5	106.2	114.9	104.1
16x24	161	88.4	110.1	107.7	101.8
16x36	253	117.3	118.8	104.7	97.4
24x36	561	125.7	108.0	103.7	96.6
30x36	920	118.2	109.6	106.6	96.6

*Data calculated from Table 41.

EFFECT OF PLANTING AT DIFFERENT RATES UPON THE GROWTH OF CORN IN POTS

In 1915, corn was planted at four different rates, namely one, two, four, and six plants in pots 16 by 36 inches in size and containing 253 pounds of soil. The results are contained in Tables 44, 45, and 46. Without manure (Table 45) the individual plants in the six, four and two-rate yielded respec-

TABLE 44—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. Hogue's Yellow Dent corn (1915)*

Rates of planting per pot	Moisture-free contents		No. pots averaged	Dry matter*		Total leaf-area per plant †	Height of stalk
	Soil	Manure		Ear	Total		
	Pounds	*Pounds*		*Grams*	*Grams*	*Sq. in.*	*Inches*
1	253		4	232	476	1334	123
1	253	1.55	8	262	539	1457	115
2	253		4	92	242	1210	120
2	253	1.55	4	118	279	1153	112
4	253		4	37	127	895	106
4	253	1.55	4	37	151	990	105
6	253		4	6.5	79.0	714	90
6	253	1.55	4	16.7	101.9	861	93

*Where more than one plant was grown in a pot, the average yield per plant is given.

†The leaf-area is not very significant inasmuch as the lower leaves died prematurely according to the rate of planting—due to malnutrition.

TABLE 45—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. The results at different rates of planting without manure are here expressed in per cent of the results from one plant per pot. Hogue's Yellow Dent corn (1915)**

Rate of planting per pot	Wt. of soil (moisture-free)	No. of pots averaged	Dsy matter per plant		Total leaf-area per plant	Height of stalk
			Ear	Total		
	Pounds		*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	253	4	100	100	100	100
2	253	4	39.7	50.8	90.7	97.5
4	253	4	15.9	26.7	67.1	86.2
6	253	4	2.8	16.6	53.5	73.2

*Data calculated from Table 44.

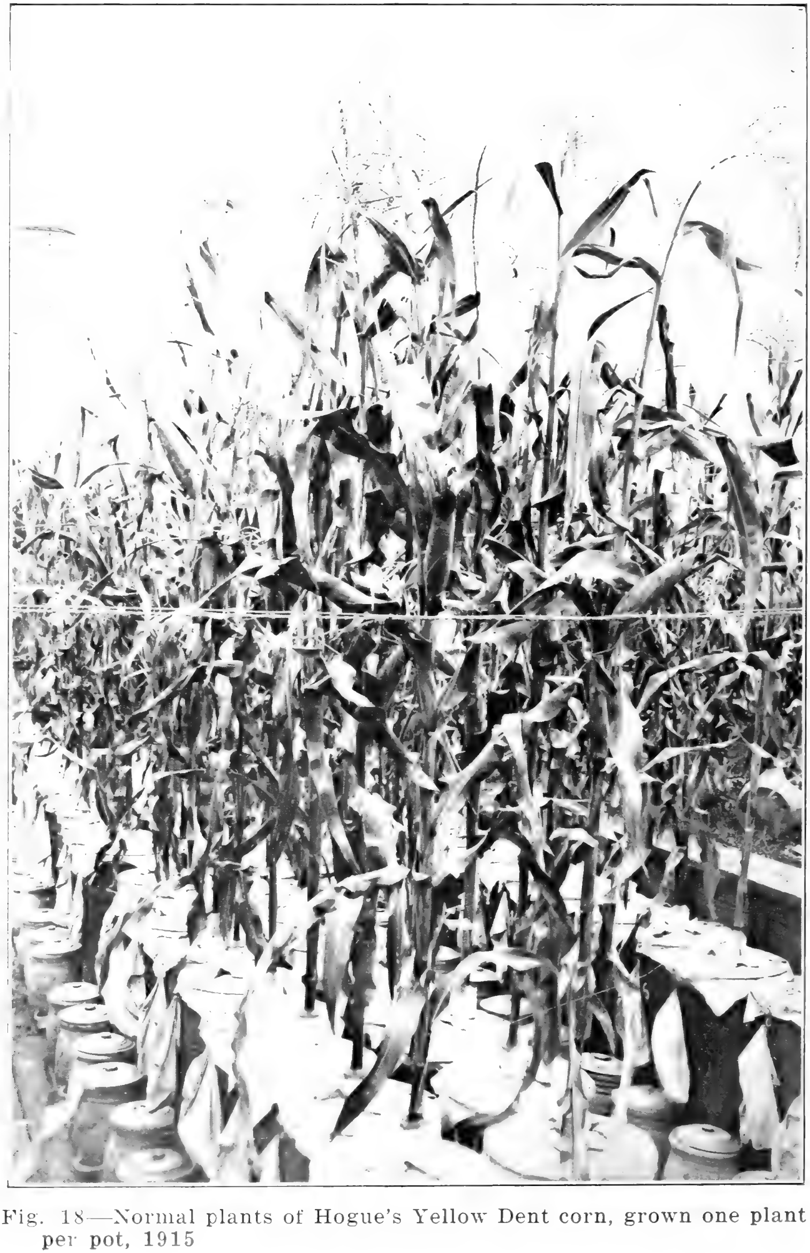
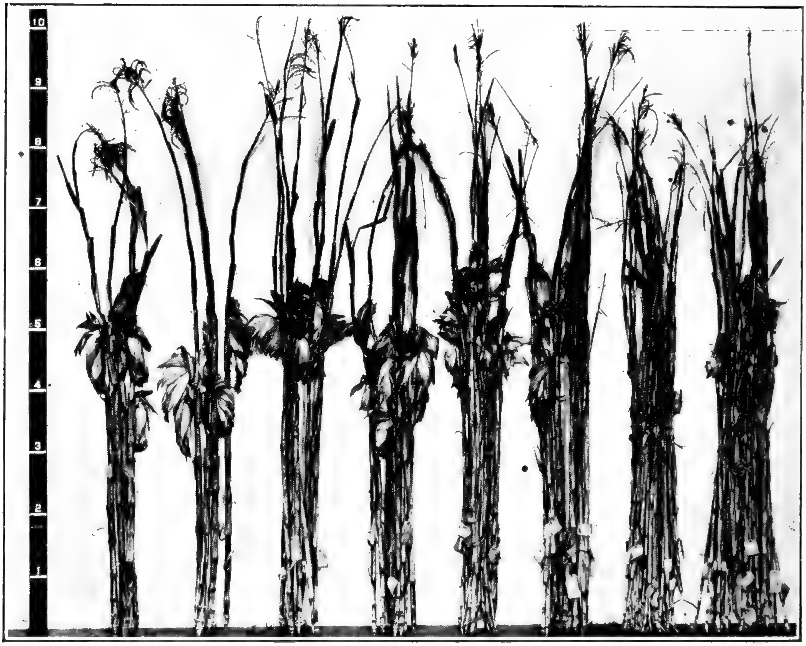


Fig. 18—Normal plants of Hogue's Yellow Dent corn, grown one plant per pot, 1915

Fig. 19—Plants in the foreground grown six, four and two plants per pot



1 2 3 4 5 6 7 8

Fig. 20---Crop harvested from four pots planted at each of the following rates per pot. Left to right, 1 and 2, one plant per pot; 3 and 4, two plants per pot; 5 and 6, four plants per pot; 7 and 8, six plants per pot. Odd numbers without manure, even numbers with manure. (Table 44.) 1914

tively 16.6, 26.7, and 50.8 per cent as much total dry matter as the one-rate, and their yield of ear corn was respectively 2.8, 15.9, and 39.7 per cent as much per plant.

An application of 1.55 pounds of manure per pot (Table 46) increased the yields of total dry matter for the one, two, four and six-rates respectively 13.2, 15.3, 18.9, and 29.0 per cent. The yields of ear corn were 112.9, 128.3, 100.0, and 257.0 per cent as large with manure as without manure in the one, two, four, and six-rates respectively.

TABLE 46—*Summary of data showing the effect of different rates of planting upon growth of corn in pots. The results at the different rates of planting with manure are here expressed in per cent of the results without manure. Hogue's Yellow Dent corn (1915)**

Rate of planting per pot	Wt. moisture-free contents		No. of pots averaged	Dry matter per plant		Total leaf-area per plant	Height of stalk
	Soil	Manure		Ear	Total		
	Pounds	*Pounds*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	253	1.55	8	112.9	113.2	109.2	93.5
2	253	1.55	4	128.3	115.3	95.3	93.3
4	253	1.55	4	100.0	118.9	110.6	99.1
6	253	1.55	4	257.0	129.0	120.6	103.3

*Data calculated from Table 44.

STATEMENT OF METHODS IN BULLETINS

A knowledge of the methods employed in crop testing is vital for intelligently evaluating the published results. Without a statement of methods, the reader is obliged to assume that reliable methods were employed. Such an assumption is not warranted, since many methods used are known to be faulty. Not only the experiment station worker but the farmer as well should be given an opportunity to know in detail how the tests were made. Increased experimentation by farmers has led many of them to be interested in methods.

The following brief summary table indicates the extent to which experiment station bulletins dealing with crop tests and published in the United States during the years 1900-1914 report details as to methods. A mere statement of results is incomplete and does not carry conviction.

TABLE 47—*Extent to which experiment station bulletins report the methods of investigation*

Method details	Per cent bulletins* reporting method details for			
	Variety tests	Fertilizer tests	Cultural tests	Pot tests
	Per cent	*Per cent*	*Per cent*	*Per cent*
Years' duration of tests	71	25	3	55
Size of plats	29	21	2	
Shape of plats	23	8	1	
Number of duplicates averaged	13	3	1	25
Distribution of duplicates	8	3		10
Use of check plats	8	11	1	20
Number of check plats	5	14	1	20
Distribution of check plats	3	5		5
Uniformity of conditions	41	21	2	40
Size of pots				55
Capacity of pots				45
Maturity of crop in pots				45

*The total number of bulletins reviewed were: variety tests, 253; fertilizer tests, 146; cultural tests, 52; pot tests, 20.

BIBLIOGRAPHY

ALWOOD, W. B., and PRICE, R. H.

1890. Suggestions Regarding Size of Plats. (Virginia Agricultural Experiment Station, Bul. No. 6, pp. 20.)

BARBER, C. W.

1914. Note on the Accuracy of Bushel Weight Determinations. (Maine Agricultural Experiment Station, Bul. 226, pp. 69-75.)

1914. Note on the Influence of Shape and Size of Plats in Tests of Varieties of Grain. (Maine Agricultural Experiment Station, Bul. 226, pp. 76-84.)

1914. Note on the Influence of Shape and Size of Plots in Tests of Varieties of Grain. (Maine Agricultural Experiment Station, Bul. 226, pp. 76-84.)

BULL, C. P.

1909. The Row Method and the Centgener Method of Breeding Wheat, Oats and Barley. (Jour. of the American Society of Agronomy, Vol. I, pp. 95-98.)

BRIGGS, L. J., and SHANTZ, H. L.

1913a. The Water Requirement of Plants. I. Investigations in the Great Plains in 1910 and 1911. (U. S. Department of Agriculture, Bureau of Plant Industry, Bul. 284, 49 pp.)

1913b. The Water Requirement of Plants. II. A Review of the Literature. (U. S. Department of Agriculture, Bureau of Plant Industry, Bul. 285, 96 pp.)

CARLETON, M. A.

1909. Limitations in Field Experiments. (Proc. Soc. Prom. Agr. Science, Vol. 30, pp. 55-61.)

COFFEY, G. N.

1913. The Purpose and Interpretation of Field Experiments. (Jour. of the American Society of Agronomy, Vol. 5, pp. 222-230.)

COLLINS, G. N.

1914. A More Accurate Method of Comparing First Generation Maize Hybrids with Their Parents. (U. S. Department of Agriculture, Jour. Agricultural Research 3, No. I, pp. 85-91.)

CORY, V. L.

1908. The Use of Row Plantings to Check Field Plats. (Jour. of the American Society of Agronomy, Vol. I, pp. 68-70.)

DAVENPORT, E.

1907. Principles of Breeding. (Boston, pp. 721.)

DAVENPORT, E., and FRAZIER, W. J.

1896. Experiments with Wheat, 1888-1895. (Illinois Agricultural Experiment Station, Bul. 41, pp. 153-155.)

FARRELL, F. D.

1913. Interpreting the Variation of Plat Yields. (U. S. Department of Agriculture, Bureau of Plant Industry, Circ. 109, pp. 27-32.)

HARTLEY, C. P., BROWN, ERNEST B., KYLE, C. H., and ZOOK, L. L.

1912. Crossbreeding Corn. (Bureau of Plant Industry, Bul. 218, 66 pp.)

HILGARD, E. W.

1901. Soil Tests and Variety Tests. (Proceedings of the Society for the Promotion of Agricultural Science, 1901, pp. 89-94.)

JARDINE, W. M.

1908. Methods of Studying the Relative Yielding Power of Kernels of Different Sizes. (Jour. of the American Society of Agronomy, Vol. I, pp. 104-108.)

KIESSELBACH, T. A.

1916. Transpiration as a Factor in Crop Production. (Nebraska Agricultural Experiment Station, Research Bul. 6, pp. 214.)

LEHN, D.

1913. New Works on Methods for Variety Testing. (Bl. Zuckerrübenbau, 20, No. 3, pp. 33-39; 4, pp. 52-55.)

LOVE, H. H.

Methods of Determining Weight per Bushel. (Jour. of the American Society of Agronomy, Vol. 7, No. 3, pp. 121-128.)

LYON, T. LYTTLETON.

1910. A Test of Planting Plats with the Same Ears of Corn to Secure Greater Uniformity in Yield. (Jour. of the American Society of Agronomy, Vol. II, pp. 35-37.)

1910. A Comparison of the Error in Yields of Wheat from Plats and from Single Rows in Multiple Series. (Jour. of the American Society of Agronomy, Vol. II, pp. 38-39.)

1911. Some Experiments to Estimate Errors in Field Plat Tests. (Jour. of the American Society of Agronomy, Vol. III, pp. 89-116.)

MERCER, W. B., and HALL, O. D.

1911. Experimental Error of Field Trials. (Jour. of Agricultural Science, No. 4, pp. 107-132.)

MONTGOMERY, E. G.

1910. Methods for Testing the Seed Value of Light and Heavy Kernels in Cereals. (Jour. of the American Society of Agronomy, Vol. II, pp. 59-70.)

1911. Variation in Yield and Methods of Arranging Plats to Secure Comparative Results. (Nebraska Agricultural Experiment Station, 25th Annual Report, pp. 164-180.)

1913. Experiments in Wheat Breeding. (U. S. Department of Agriculture, Bureau of Plant Industry, Bul. 269, pp. 60.)

MORGAN, J. OSCAR.

1908. Some Experiments to Determine the Uniformity of Certain Plats for Field Tests. (Jour. of the American Society of Agronomy, Vol. I, pp. 58-67.)

PEARL, R., and MINER, J. R.

1914. A Table for Estimating the Probable Significance of Statistical Constants. (Maine Agricultural Experiment Station, Bul. 226, pp. 85-88.)

PIPER, C. V., and STEVENSON, W. H.

1910. Standardization of Field Experimental Methods in Agronomy. (Jour. of the American Society of Agronomy, Vol. II, pp. 70-76.)

PRICHARD, F. J.

1916. The Use of Checks and Repeated Plantings in Varietal Tests. (Jour. of the American Society of Agronomy, Vol. 8, pp. 65-81.)

SALMON, CECIL.

1913. A Practical Method of Reducing Experimental Error in Varietal Tests. (Jour. of the American Society of Agronomy, Vol. V, pp. 182-184.)

1914. Check Plats—A Source of Error in Varietal Tests. (Jour. of the American Society of Agronomy. Vol. 6, pp. 128-131.)

SCHNEIDEWIND, W.

1914. Experiments with Different Sized Plats. (Mitt. Deut. Landw. Gesell, 29, No. 21, pp. 298-300.)

SCHOLZ, H.

1910. Methods of Conducting Variety Tests. (Fühling's Landw. Ztg. 59, No. 22, pp. 776-785; and No. 23, pp. 807-830.)

SPRAGG, FRANK A.

1910. Methods of Keeping Crop Records at Michigan Experiment Station. (Jour. of the American Society of Agronomy, Vol. II, pp. 43-55.)

SMITH, LOUIS H.

1909. Plot Arrangement for Variety Experiments with Corn. (Jour. of the American Society of Agronomy, Vol. I, pp. 84-89.)

STOCKBERGER, W. W.

1916. Relative Precision of Formulae for Calculating Normal Plot Yields. (Journal of the American Society of Agronomy, Vol. 8, pp. 167-175.)

SURFACE, F. M., and PEARL R.

1916. A Method for Correcting for Soil Heterogeneity in Variety Tests. (U. S. Department of Agriculture, Jour. of Agr. Research, Vol. 5, No. 22, pp. 1039-1049.)

TAYLOR, F. W.

1908. The Size of Experiment Plots for Field Crops. (Jour. of the American Society of Agronomy, Vol. I, pp. 56-58.)

THORNE, CHAS. E.

1908. The Interpretation of Field Experiments. (Jour. of the American Society of Agronomy, Vol. I, pp. 45-55.)

1909. Essentials of Successful Field Experimentation. (Ohio Agricultural Experiment Station, Circular 96, pp. 38.)

VINALL, H. N., and ROLAND, McKEE.

1916. Moisture Content and Shrinkage of Forage and the Relation of These Factors to the Accuracy of Experimental Data. (U. S. Department of Agriculture, Bul. 353.)

VON RUMKER, LEIDNER, K. R., and ALEXANDROWITSCH, J.

1914. The Application of a New Method for Testing Cereal Varieties and Selections. (Ztschr. Pflanzenzucht, 2, No. 2, pp. 189-232.)

WHEELER, H. J.

1908. Some Desirable Precautions in Plat Experimentation Work. (Jour. of the American Society of Agronomy, Vol. I, pp. 39-44.)

WOOD, T. B., and STRATTON, F. J. M.

1910. Interpretation of Experimental Results. (Jour. of Agricultural Science, 3, 417-440.)

WIANCKO, A. T.

1914. Use and Management of Check Plats in Soil Fertility Investigations. (Jour. of the American Society of Agronomy, Vol. 6, pp. 122-124.)

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